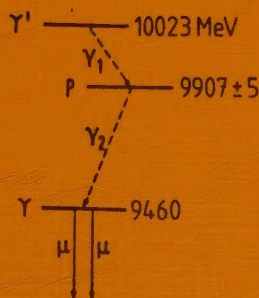
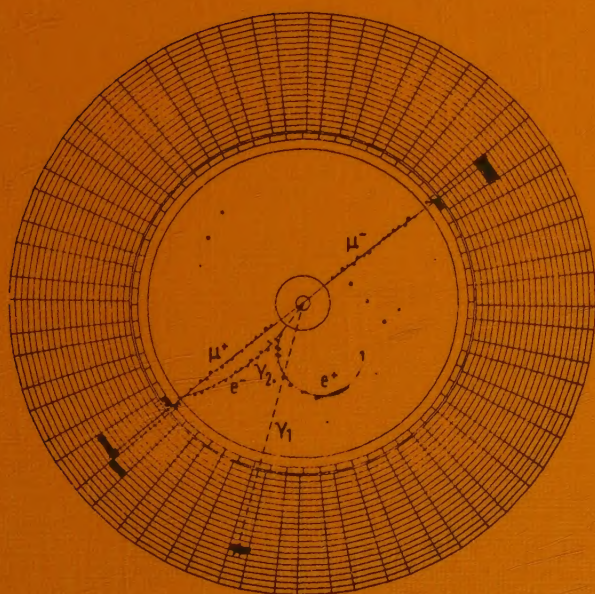


STUDY OF Υ MESONS PRODUCED IN $e^+ e^-$ COLLISIONS AT DORIS

Peter Böckmann

ARGUS



LUND 1983

A STUDY OF τ MESONS PRODUCED IN e^+e^- COLLISIONS AT DORIS

By due permission of the faculty of mathematics and natural sciences of the University of Lund to be publicly discussed at the lecture hall B of the Department of Physics, December 7th, 1983, at 13:15 p.m., for the degree of doctor of philosophy.

by

Dirk-Peter B ö c k m a n n

Fil. Kand.

Lund 1983



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Abstract
 This thesis concerns the observation of the Upsilon mesons at the electron positron storage ring DORIS at DESY. The studies were carried out with the double arm spectrometer DASP and with the solenoid spectrometer ARGUS. The results show that the Upsilon mesons can be interpreted as bound states of a new heavy quark and its antiquark partner. The properties of these quark antiquark pair resonances are well understood in terms of QCD.

Key words Vector meson, quark antiquark production, gluon, QCD, storage ring, DORIS, particle identification

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A STUDY OF T MESONS PRODUCED IN e^+e^- COLLISIONS AT DORIS

by

Peter Böckmann

LUND 1983

This thesis in high energy physics is based on the following papers:

- I. H. Albrecht et al., A DETERMINATION OF THE TOTAL WIDTH
OF THE $T(9.46)$ MESON
- II. H. Albrecht et al., THE HADRONIC CROSS SECTION OF
ELECTRON-POSITRON ANNIHILATION
AT 9.5 GeV AND THE T AND T'
RESONANCE PARAMETERS
- III. D. P. Barber et al., A PRECISION MEASUREMENT OF THE T' MASS
- IV. H. Albrecht et al., INCLUSIVE HADRON PRODUCTION IN THE
 T REGION
- V. H. Albrecht et al., BRANCHING RATIO AND MASS SPECTRUM OF
THE DECAY $T' \rightarrow T\pi^+\pi^-$

My main contributions to the DASP2 experiment were to fit the hadronic resonance curves properly taking into account the radiative corrections, to determine the branching fraction for the T decaying into muon pairs and to investigate the topological differences between the resonances and the continuum.

At ARGUS I developed a simulation program, which generated events of various topologies and which traced the resulting particles through the detector taking into account different physical processes such as scattering, absorption and electromagnetic processes. As these simulated particles were traced through the detector, the responses of the various components were digitized and written out on tape in exactly the same format as real data. In addition I developed the three dimensional pattern recognition algorithm for the ARGUS analysis program. I also wrote the software for the data transfer between the online computer and the main computer centre where the data was automatically dumped on tape at regular intervals. Further I worked on the analysis of the $T' \rightarrow T\pi^+\pi^-$ decay. Finally I developed the techniques, which identified tracks in the drift chamber from converted photons. I then employed these methods to study electromagnetic decays of the T' meson.

INTRODUCTION

During the last decade studies of e^+e^- interactions have led to a better understanding of the structure of matter and of the fundamental forces involved.

Bound states of heavy quarks and their antiquarks, like the J/ψ or Υ mesons, are easily formed in e^+e^- annihilations. Since these mesons can be regarded as the "hydrogen atom" of quark antiquark interactions the study of their properties is of fundamental interest. The $\Upsilon(9460)$ and $\Upsilon(10020)$ mesons were observed for the first time as narrow resonances in e^+e^- annihilations at the DORIS storage ring at DESY. The results obtained with the DASP2 detector between 1978 and 1980 are presented in papers I, II and IV. More refined investigations of these resonances became possible with the ARGUS detector which came into operation at the improved DORIS storage ring at the end of 1982. First results from this new experiment are published in papers III and V.

The aim of this presentation is to review the underlying physics for making these studies and to give the main features of the experiments. Finally I will discuss the results obtained in the framework of the theory of strong interactions, called Quantum Chromo Dynamics (QCD).

PHYSICS BACKGROUND

In 1974 the J/ψ resonance was discovered at BNL(1) and SLAC(2) as a narrow resonance at a mass of 3.1 GeV. Its unexpectedly long lifetime was qualitatively understood by the fact that the J/ψ represents a bound state of a previously undiscovered quark c with its antiquark $\bar{c}$. These quarks carry a quantum number called charm which has to be conserved in strong interactions. Since a decay into mesons containing charmed quarks is kinematically not allowed the main decay of such a $c\bar{c}$ state must therefore proceed via a $c\bar{c}$ annihilation into three gluons. This proceeds slowly and leads to the observed narrow width. The existence of this fourth quark had been predicted in 1970 by Glashow, Iliopoulos and Maiani (3), who invented the so called GIM mechanism in order to explain the absence of strangeness changing neutral currents in K^0 decay.

Further investigations of $c\bar{c}$ spectroscopy and of D mesons (4) containing either a c or a $\bar{c}$ quark at the e^+e^- storage rings SPEAR and DORIS showed that the c quark is in the same left handed quark doublet as the strange

quark. This second generation of quarks (s,c) is related to the first generation quark doublet (u,d) by the Cabibbo angle. Since, at this time only two generations of leptons were known, namely the (e,ν_e) and (μ,ν_μ) doublets, the quark lepton symmetry was inferred.

With the discovery of the τ lepton in 1975 at SPEAR (5) and its presumed neutrino ν_τ , the quark lepton symmetry appeared once more to be broken. In order to reestablish it another generation of quarks was needed. Kobayashi and Maskawa (6) had already proposed in 1973 a theory containing six quarks in three doublets. The quarks of the third generation were called b (bottom) for the charge $-1/3$ member and t (top) for the charge $+2/3$ member. Another consequence of this theory was that CP violation could be described in a natural way.

The first hint of the existence of a new heavy quark came in 1977 from the observation of an excess of events at 9.5 GeV in the dimuon mass spectrum. The data came from a study of p + Be collisions at FNAL (7). The spectrum was fitted by three resonances (8), each with a width consistent with the experimental mass resolution of 200 MeV. This, together with the large leptonic branching ratio, indicated that these resonances named Υ (Upsilon), Υ' and Υ'' were very narrow. In similar fashion to the J/Ψ , these states were interpreted as bound states of another new heavy quark and its antiquark. These studies could be ideally pursued at e^+e^- storage rings, where the energy resolution is of the order of a few MeV. Under these conditions a more detailed investigation of these states becomes possible. At this time DORIS at DESY was the only e^+e^- storage ring which, after some modifications could reach this energy range. The four groups DASP2, PLUTO and later DESY-Heidelberg and LENA used this facility to confirm the existence of the Υ and Υ' as narrow resonances at 9.46 and 10.02 GeV. Studies of the leptonic decays showed that the Υ mesons were bound 3S_1 states of b and $\bar{b}$ quarks. The determination of the total width and the investigation of the hadronic decay topologies showed the dominance of the three gluon decay of the Υ meson (9, paper I, II and IV).

Further studies became possible when the storage ring CESR came into operation at Cornell in 1979. Two experimental groups CUSB and CLEO were able to investigate the third Υ state (10). They also found the $\Upsilon(4S)$ state at 10.6 GeV (11). The observed width was larger than the experimental resolution, which indicated that this state lay above the threshold for decaying into a pair of B mesons ($B = b\bar{u}, b\bar{d}$). The B mesons can themselves be used to study weak decays and many predictions made by the standard electroweak theory have been confirmed by the work at CESR (12).

In analogy to the hydrogen atom, transitions between the various Υ states are possible. Gluonic transitions between the S states are allowed as well as radiative transitions from S to P states and vice versa. As an example of a gluonic transition the Υ' is allowed to decay into the Υ by emission of two pions. The decay has been investigated by LENA, CUSB, CLEO and recently also by ARGUS (13, paper V and references therein). The intermediate

triplet P states are produced by the emission of a photon from a higher mass 3S_1 state. First results on these radiative transitions have been presented by CUSB, CLEO, ARGUS and the CRYSTAL BALL (14, fig.1). The results show the presence of three triplet P states in the mass range both between the T'' and T' and between the T' and T .

DORIS

The e^+e^- storage ring DORIS shown in fig. 2 started operating in 1974. Electron positron collisions occurred in two intersection regions. The original setup stored electrons and positrons in separate beam tubes because DORIS was operated as a multibunch machine. The reason for this was that better luminosity is obtained at low energy with a multibunch operation. However at higher energies it is more favourable to operate in a single bunch mode. During its upgrading in 1977, DORIS was therefore changed to operate as a single bunch machine. As a consequence, it was possible to store electrons and positrons in the same beam tube. Typical luminosities achieved were about 30 events/nb. DORIS was upgraded once more in 1982 in order to reach the $T(4S)$ resonance and the maximum attainable energy is at present around 11 GeV. Typical luminosities were 500 events/nb and typical beam lifetimes were around 3 hours.

THE DETECTORS

DASP

The DASP detector, fig.3, consisted of a nonmagnetic inner detector with scintillator-lead-proportional tube counters which covered about 70% of 4π . Particle separation was only possible between photons, minimum ionising and showering particles. The proportional tubes allowed a measurement of the positions of the tracks and the showers.

In addition to the inner detector there were also two spectrometer arms which covered only 5% of 4π . These were equipped with sets of spark chambers on both sides of a spectrometer magnet, time of flight counters, cerenkov counters, shower counters and range counters to provide a separation between electrons, muons, pions, kaons and protons. Details of the detector are presented in ref. (15).

The detector was divided into eight octants as shown in fig.3. The triggers used were defined by demanding coincidences between different octants (16).

Data analysis

The inner detector analysis was done essentially in three steps. From the arrangement of the scintillation counters it was possible to make a fast analysis by defining roads along the tracks. The proportional tubes were used to find the points on the tracks and then all the fitted tracks were combined to find a common vertex after which a vertex constraint track fit was done. The outer detector analysis was done independently from the inner one. The spark chambers were used to measure track coordinates in the outer detector. By combining the inner and outer detector information and also the deflection by the magnet, it was possible to measure the particle momentum.

ARGUS

ARGUS fig. 4 is a solenoid spectrometer with a magnetic field of 0.8 T consisting of a cylindrical drift chamber, a time of flight system, a shower detection system and a muon identification system (17).

The drift chamber consists of 36 concentric cylindrical layers in a volume 2 m long and 1.6 m in diameter. Wires parallel to the z axis give the cylindrical coordinates ρ and ϕ of the tracks.

In addition there are small angle stereo layers to determine the z coordinate of the track. In total there are 5940 sense wires. The chamber is operating at atmospheric pressure with a mixture of 97% propane and 3% methylal. The distance d from a track to a wire hit is in general a complicated function of many parameters $d = d(t, \vartheta, z, B)$ where t is the drift time information, ϑ the angle between the track and the radius vector inside one cell, z is measured along the beam axis and B is the magnetic field. For tracks with more than 20 hit wires it turns out that a fit using a parametrisation $d = d(t)$ yielded an average resolution of 180 μm . Such a simple relation results mainly from the square cell structure and from the homogeneity of the magnetic field. The drift chamber also allows particle identification via the simultaneous measurement of the specific ionization loss and the momentum of the track. The drift chamber is surrounded by scintillation counters for time of flight measurements. There are 64 barrel counters viewed by phototubes from both ends and 96 endcap counters each viewed only by one phototube. The measured time resolution is around 180 ps. The photon detection system consists of 1760 shower counters mounted inside the magnet coils. This arrangement is very important for the detection of low energetic photons.

The counters have a lead scintillator sandwich structure with wavelength shifter read outs and have a measured energy resolution of about 7.5% for 1 GeV electromagnetic showering particles. In order to identify muons, the detector is finally surrounded by a muon detection system consisting of 1744 proportional tubes mounted both inside and outside the yoke.

Data reduction

The data reduction essentially relies on the track reconstruction in the drift chamber. This starts with the pattern recognition in the drift chamber in order to find charged tracks. One big advantage is the reliability of the pattern recognition because of the simple drift time space relation mentioned above. After the pattern recognition the track parameters are already sufficiently reliable to make efficient cuts to reject most of the background events. The pattern recognition operates in the plane perpendicular to the beam direction, using the axial wire information. Due to the homogeneity of the magnetic field the tracks in the first approximation can be treated as segments of circles. For each segment the parameters of the circle are calculated and an extrapolation to the point closest to the beam axis is done. In order to remove beam gas and beam wall events at least one track is required to point to the vertex region. The projection of a track has a helix pattern in the r - z plane, where r is the radius and z is measured along the beam axis. Such patterns are looked for to obtain the remaining track parameters and a cut in the z coordinate of the track at the point closest to the beam axis is introduced to remove further background events. Acceptable events are required to have at least one track surviving these cuts. The remaining data comprises mainly Bhabha and $\gamma\gamma$ events, real annihilation multihadron events, two photon events and some beam wall and beam gas background. The next step is a more time consuming five parameter track fit. The results from this fit are then used to extrapolate the tracks back to find a common vertex. A constrained vertex trackfit is attempted to obtain the final track parameters. In order to get a clean sample of multihadrons and to remove the Bhabha events, each event in our final sample is required to have three or more tracks, at least two of which are required to point to the interaction vertex. After this step, the data is written on a DST for physics analysis. The filtered data contains mostly multihadron events. Contributions to the background come from radiative Bhabhas with converting photons, beam wall interactions and two photon events.

RESULTS

The results of the experiments published in paper I, II and III were mainly concerned with the observation of the Υ and Υ' mesons and their resonance parameters. Of particular importance was the observation of the very narrow total width of the Υ meson, which could be explained by QCD. The Υ meson decays mainly via the annihilation of the b and the $\bar{b}$ quarks into three gluons. This decay rate is governed by the value of the strong coupling constant α_s (18). From the total width we measured $\alpha_s = 0.17^{+0.04}_{-0.03}$ (paper I) in good agreement with other measurements.

Since the b quarks are heavy they are moving relatively slowly inside the Υ meson. A description of this system could therefore be given by the non relativistic Schrödinger equation, as was done for positronium and hydrogen. However, instead of the coulombic interaction, a potential describing the strong interaction must be used in the Schrödinger equation. This potential has to reflect the observed behavior of quarks, namely the asymptotic freedom at small distances and the quark confinement at large separation of the quarks. Qualitatively this yields a Coulombic behavior of the potential at small distances and a linear form at large distances (19). The calculations involving such potentials in fact show good agreement with the data. If the potential is described at intermediate distances by a logarithmic form, the mass differences and leptonic widths of the Υ mesons are reasonably well reproduced (20). The accuracy of the mass measurements σ_M/M of $6 \cdot 10^{-5}$ (paper III), however, represents a big challenge for such calculations. The flavour independence of $q\bar{q}$ interactions is demonstrated by the fact that both the Ψ and Υ systems can be described by the same potential, as is also shown by the inverse scattering formalism (21).

The hadrons from Υ decay come mainly from the hadronisation of an intermediate three gluon state, whereas processes in the continuum are dominated by fragmentation of quark antiquark pairs. The study of event topologies on and off resonance can therefore uncover differences between these processes and thereby help to elucidate the nature of gluons. Indeed we find small differences in the invariant cross sections and the hadron multiplicities. These differences are in agreement with what is expected from gluon and quark fragmentation models. The most prominent difference is found in the production of protons which is more abundant in Υ and Υ' decays (paper IV). This effect has also been observed in J/Ψ decays and in the reaction $e^+e^- \rightarrow \text{hadrons}$ at energies around 30 GeV where gluon bremsstrahlung becomes important.

The transition $\Upsilon' \rightarrow \Upsilon \pi^+ \pi^-$ was investigated with high statistics and high resolution for the first time by the ARGUS experiment (paper V). This decay is assumed to take place by emission of two gluons from the Υ' which then hadronize into two pions. In a lowest order QCD multipole expansion the shape of the invariant $\pi^+ \pi^-$ mass spectrum can be

calculated. The measured $\pi^+\pi^-$ invariant mass spectrum shows a behavior very much different from pure phase space thus revealing the dynamics of this process. A comparison between the data and the theory show that the QCD model describes also this transition very well.

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I gratefully acknowledge the help I have recieved from all my collaborators and the people at my home institute. Specially I want to thank H. Albrecht, R. Davis, L. Jönsson, W. Schmidt-Parzefall, H. Schröder and K. R. Schubert for their effort and fruitful discussion in preparing this thesis. Finally I am grateful to my wife for her encouragement and support.

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FIGURE CAPTIONS

Fig 1. The inclusive spectrum of converted photons
measured on the T' meson

Fig 2. A schematic view of DESY and DORIS

Fig 3. The DASP detector

Fig 4. The ARGUS detector

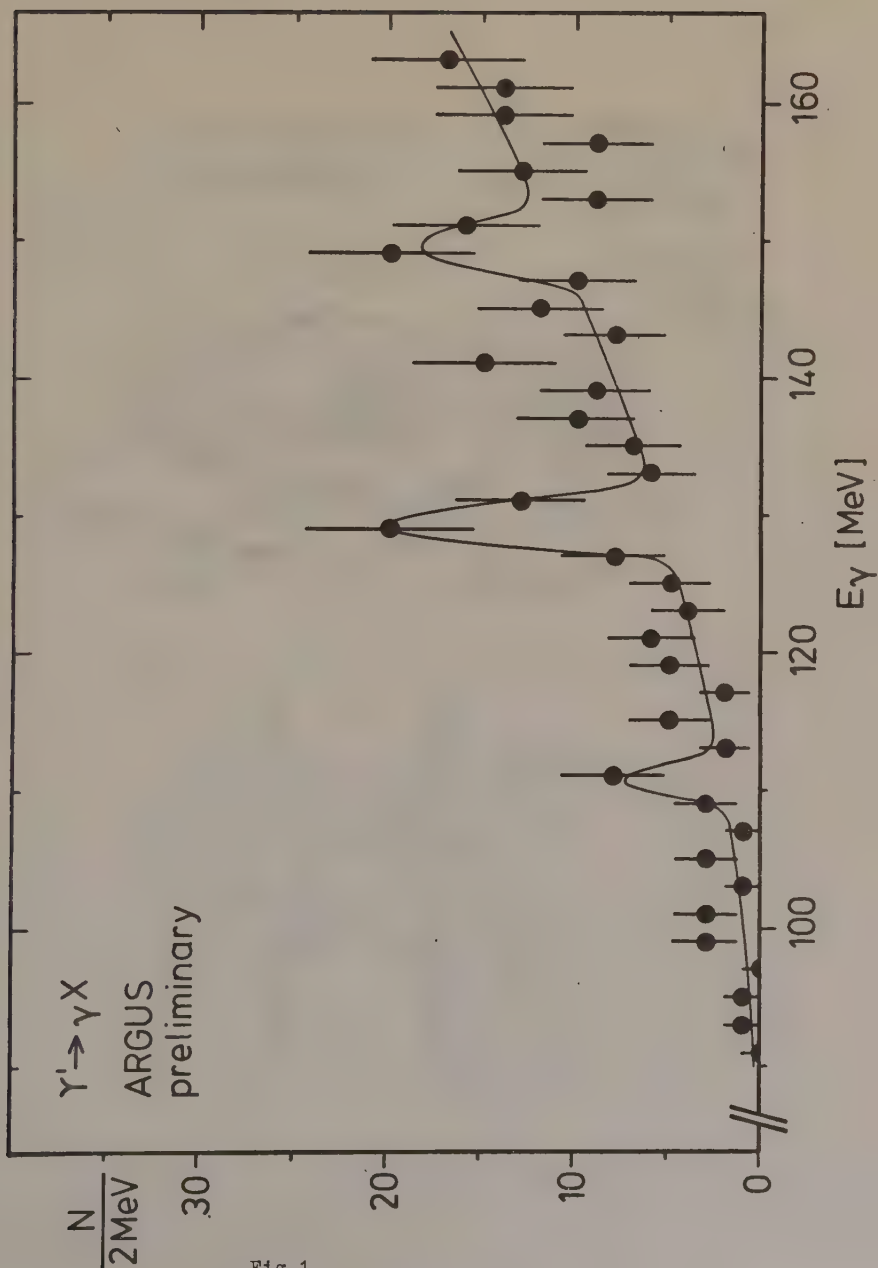


Fig 1.

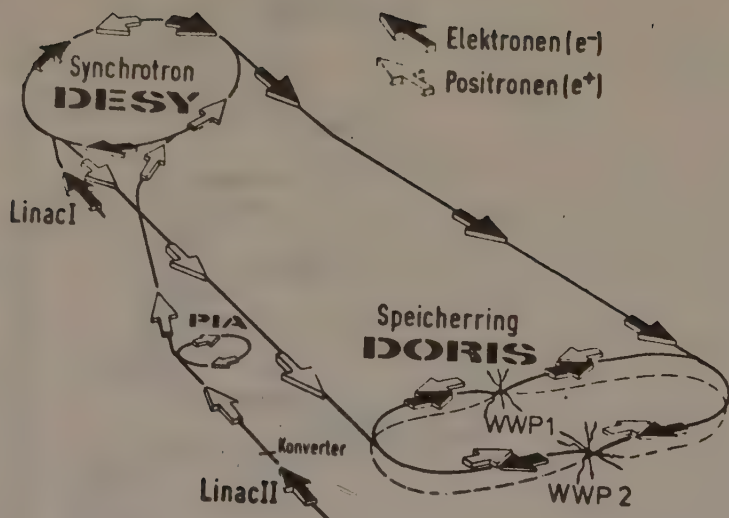


Fig 2. View of DESY and DORIS

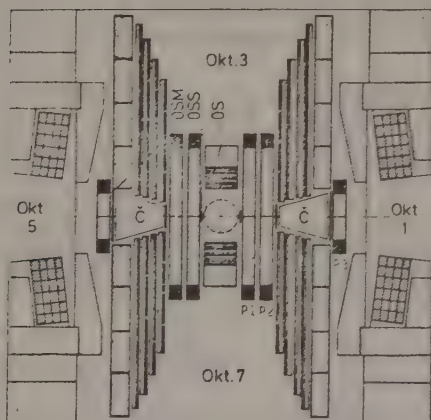
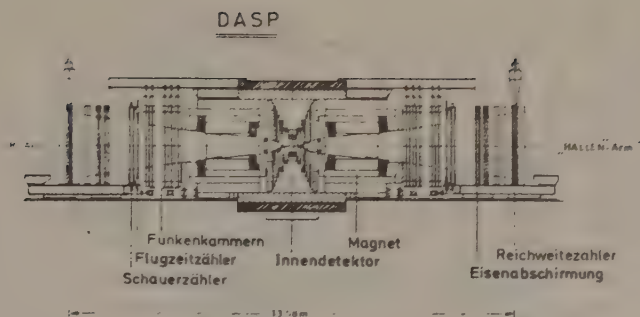


Fig 3. The DASP detector viewed along the beam axis

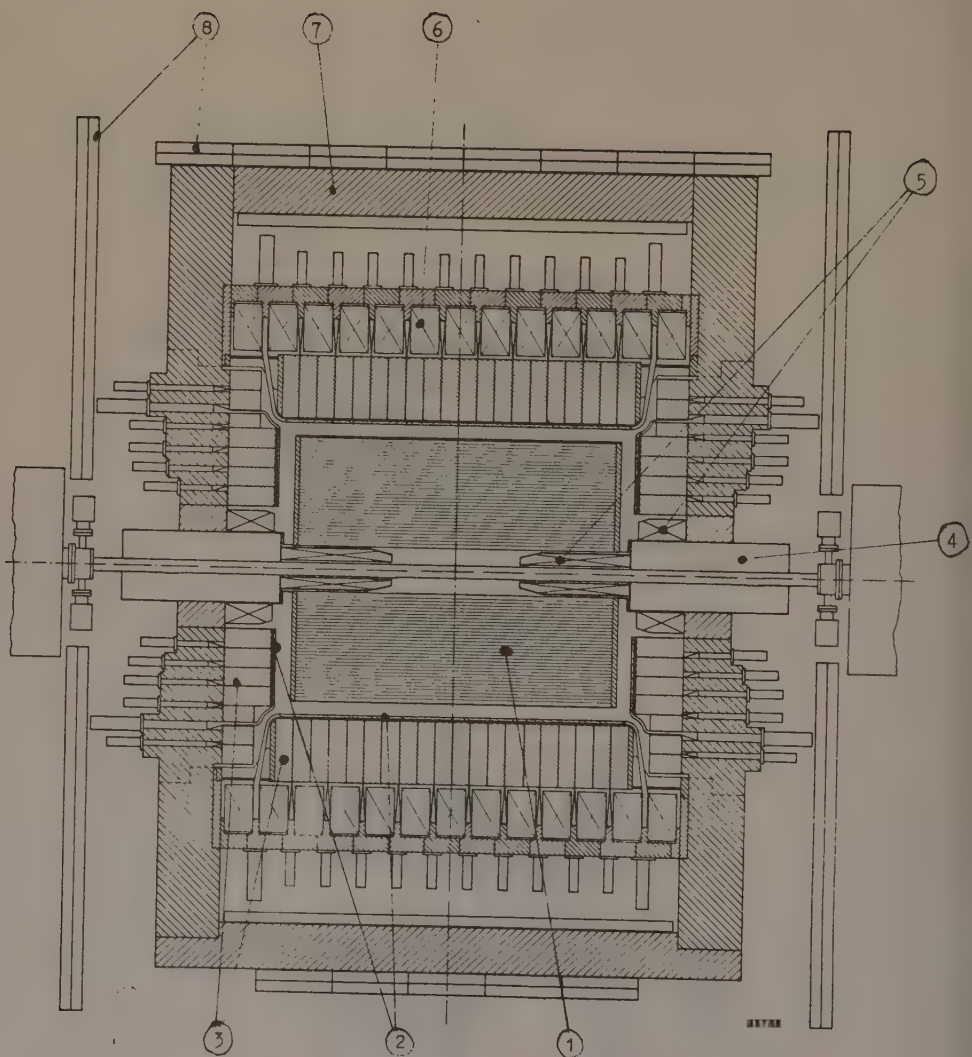


Fig 4. The ARGUS detector

- 1) Drift chamber
- 2) Tof system
- 3) Shower counters
- 4) Mini beta quad.
- 5) Compensation coil
- 6) Solenoid coils
- 7) Iron yoke
- 8) Muon chambers

A DETERMINATION OF THE TOTAL WIDTH OF THE $\Upsilon(9.46)$ MESON

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Using the DASP detector at the DESY storage ring DORIS we have continued measuring e^+e^- annihilations near and on the $\Upsilon(9.46)$ resonance. From the cross sections for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow$ hadrons we obtain a $\mu^+\mu^-$ branching ratio for the $\Upsilon(9.46)$ of $(2.9 \pm 1.3 \pm 0.5)\%$, a leptonic width $\Gamma_{ee} = (1.35 \pm 0.11 \pm 0.22)$ keV and a total width of (47^{+37}_{-15}) keV.

The $\Upsilon(9.46)$ meson was discovered in hadronic production in its $\mu^+\mu^-$ decay mode [1] and was subsequently seen in electron-positron annihilations at DORIS [2-4]. A direct determination of its total width Γ_{tot} is possible neither in hadronic production nor with e^+e^- storage rings, since Γ_{tot} is much smaller than the resolutions obtainable with spectrometers and the energy widths of storage ring beams. Therefore, the only practicable method for determining Γ_{tot} is given by

$$\Gamma_{\text{tot}} = \Gamma_{ee}/B_{\mu\mu}, \quad (1)$$

where $\Gamma_{ee} = \Gamma(\Upsilon \rightarrow e^+e^-)$ is found from the excitation curve $e^+e^- \rightarrow \Upsilon \rightarrow$ hadrons and $B_{\mu\mu}$ is the muon

pair branching ratio. From lepton universality, $\Gamma_{ee} = \Gamma_{\mu\mu}$ is assumed in eq. (1).

Using all data from the 1978 DORIS run, the three experimental groups could determine only rough values for the muonic branching ratio $B_{\mu\mu}$: $(2.5 \pm 2.1)\%$ [5], $(2.2 \pm 2.0)\%$ [6] and $(1.0^{+3.4}_{-1.0})\%$ [7]. Even the combination of these three results is not sufficiently accurate to give reasonable limits on Γ_{tot} . It was therefore highly desirable to aim at a more precise value for $B_{\mu\mu}$.

From October to December 1979, a new DORIS run in the centre-of-mass energy range from 9.40 to 9.60 GeV allowed us to collect more data for this purpose. We report here on two independent analyses of the $\mu^+\mu^-$ data, one obtained with the DASP inner detector and the other with the DASP outer detector.

The Double Arm Spectrometer DASP has been de-

¹ On leave from the University of South Carolina, USA.

² On leave from the University of Iowa, USA.

scribed before [8]. Its non-magnetic inner detector consists of scintillation counters, lead converters, proportional tube counters and scintillator-lead-sandwich shower counters; it covers a solid angle of about $0.50 \cdot 4\pi$. Its last layer of scintillation counters is equipped for a particle time-of-flight determination, with an average distance of 1 m from the interaction point at a time resolution of $\sigma = 1.1$ ns. The magnetic outer detector consists of two spectrometer arms equipped with spark chambers, Cerenkov counters, scintillators, sandwich shower counters and range counters behind an iron shield for muon identification. Both arms together cover a solid angle of about $0.05 \cdot 4\pi$.

DORIS was operated in a single-ring, single-bunch mode and accumulated electron and positron currents of typically 18 mA each with a typical life time of 4 h. The refill time was usually only several minutes. Peak luminosities were about $10^{30}/\text{cm}^2 \text{ s}$ and average luminosities about $30/\text{nbday}$. The luminosity was measured by a counter system at scattering angles of 8° to record small angle Bhabha scattering. It was independently determined by large angle Bhabha scattering in the inner detector and also in the outer detector as will be described below.

We start by discussing the outer detector analysis. For an integrated luminosity of $676/\text{nb}$ ($410/\text{nb}$ on and $266/\text{nb}$ near the Υ resonance) we collected a total of 6990 two-arm-triggers. After demanding at least one reconstructed track in each arm and applying cuts for collinearity, vertex position, time of flight, Cerenkov signals, shower counter energies and acceptance region, there remain 252 events. Deviations from collinearity had to be smaller than 80 mrad in the magnetic bending plane and 40 mrad normal to the bending plane; the acceptance region was defined by $|\cos \theta| < 0.5$ and $|\tan \phi| < 0.148$. The 252 events contain 218 identified Bhabha events and 34 identified $\mu^+\mu^-$ events. By demanding only opposite scintillation counter information and by not requiring reconstructed tracks, one additional $\mu^+\mu^-$ event was found. The number of muon pair events on the Υ resonance is $N_{\mu\mu}^{\text{on}} = 24$ and near the resonance $N_{\mu\mu}^{\text{off}} = 11$.

The muonic branching ratio is given by

$$B_{\mu\mu} = \frac{\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+\mu^-)}{\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \text{hadrons}) + 3\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+\mu^-)} \quad (2)$$

where the denominator takes into account e , μ and τ

pair decays through lepton universality. A measurement of $e^+e^- \rightarrow \mu^+\mu^-$ at the peak energy of the resonance yields events from Υ decay and from the QED continuum. The continuum contribution, apart from its $1/W^2$ dependence, is equal to the rate near the resonance. To determine $\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+\mu^-)$ one may either subtract the *observed* cross section near the resonance or the *expected* QED cross section at the resonance energy. The second method has been applied for this outer detector analysis using the observed number of e^+e^- events at the resonance energy. There are 135 events identified as e^+e^- events at the resonance energy in the outer detector. Taking into account the detection efficiency, the radiative corrections, a small $e^+e^- \rightarrow \Upsilon \rightarrow e^+e^-$ contribution, and multiplying by the QED ratio for muon pairs relative to electron pairs, we expect $N_{\mu\mu}^{\text{QED}} = 14.3 \pm 2.0$. Continuum muon pairs at the resonance energy. This value is compatible with the observed number $N_{\mu\mu}^{\text{off}}$. $L(\text{on})/L(\text{off}) = 16.9 \pm 5.1$, where L are the integrated luminosities. We assume unpolarized beams in the storage ring and use the fact that the angular distribution for $e^+e^- \rightarrow \Upsilon \rightarrow \mu^+\mu^-$ is equal to the corresponding QED distribution to obtain

$$\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+\mu^-) = \frac{N_{\mu\mu}^{\text{on}} - N_{\mu\mu}^{\text{QED}}}{N_{\mu\mu}^{\text{QED}}} \cdot \sigma_{\mu\mu}^{\text{QED}} = (0.68 \pm 0.40) \text{ nb} \quad (3a)$$

This result includes the DORIS energy resolution and radiative corrections to the resonance height. However, the corresponding hadronic cross section in eq. (2) includes exactly the same factors and we do not need to unfold both for a determination of $B_{\mu\mu}$.

The method of analysis described for the outer detector is independent of a separate luminosity measurement. The luminosity information enters only via the observed number of Bhabha events in the outer detector at the resonance energy. Cross checks with the 8° monitor and with Bhabha events in the inner detector show agreement within the statistical errors of $\pm 7\%$.

The inner detector analysis relies on the shower counter and the time-of-flight measurement. Every event with two reconstructed non-showering tracks which are collinear and are determined not to be a single traversing cosmic ray is taken as a $\mu^+\mu^-$ event. This is justified by the result in the outer detector

that no single hadron pair was found in the sample with 10 events of genuine $\Upsilon \rightarrow \mu^+ \mu^-$ decays.

For an integrated luminosity of 818/nb (300/nb on the resonance and 518/nb at neighbouring energies including the energy range 9.90–10.00 GeV), there were 261 000 pair triggers in the inner detector. The trigger required two roughly collinear scintillator roads to be hit. In the reconstruction, we required two non-showering tracks in the proportional tube chambers with a collinearity deviation $\cos \alpha < 0.98$, a shower counter cut $E < 2.2$ GeV per track and an event time within ± 10 ns of the DORIS bunch crossing time. For the remaining events, the time-of-flight difference Δt between two opposite scintillators, on the average at a distance of one meter from the interaction point, is shown in fig. 1a. There is a clear peak at $\Delta t = 0$ from genuine $\mu^+ \mu^-$ events sitting on the tail of the very abundant cosmic rays. A cut -1.4 ns $< \Delta t < 1.8$ ns results in 93 muon pair candidates on the resonance and 132 near the resonance. The numbers of background cosmic rays in these samples are estimated from the Δt distribution of events in a 60 ns wide event time range away from the DORIS bunch crossing time as shown in fig. 1b. There are 9.0 ± 1.7 background events on the resonance and 23.3 ± 2.8 nearby. Using the integrated luminosities from the

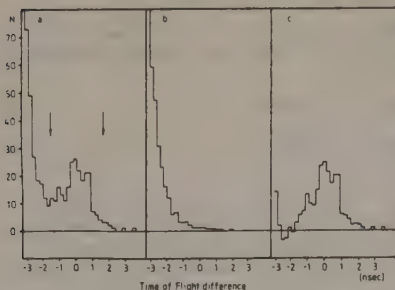


Fig. 1. Distribution of the time-of-flight difference between two opposite scintillation counters for the selected sample of events with two collinear non-showering tracks in the inner detector, (a) for the events within ± 10 ns of the bunch crossing time, (b) for background events in a 60 ns wide control region away from the bunch crossing time, (c) for muon pair events after subtraction of the background events. The arrows indicate the cuts chosen.

number of reconstructed Bhabha events in the inner detector, the number of observed muon pair events near the resonance and the QED cross section for $e^+e^- \rightarrow \mu^+ \mu^-$, we obtain an overall acceptance for muon pairs of $(22.5 \pm 2.4)\%$. Applying this value to the observed number of events on the resonance, we obtain

$$\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+ \mu^-) = (0.27 \pm 0.20) \text{ nb} . \quad (3b)$$

Fig. 2 shows the $\cos \theta$ distribution of the observed muon pair events corrected for acceptance as obtained from a Monte Carlo simulation with all trigger and reconstruction criteria. Since the charge of the muons is not determined in the inner detector, the distribution shows only $|\cos \theta|$. It compares well with the expected $(1 + \cos^2 \theta)$ distribution.

Since the results for the outer and the inner detector, as given in eqs. 3a and 3b, are independent of each other, we average them and obtain

$$\sigma(e^+e^- \rightarrow \Upsilon \rightarrow \mu^+ \mu^-) = (0.35 \pm 0.18) \text{ nb} . \quad (3c)$$

The hadronic cross section entering in eq. (2) has been determined from the same sample of events collected in 1979. Fig. 3 shows the observed cross section for $e^+e^- \rightarrow \text{hadrons}$ with ≥ 4 reconstructed particles in the inner detector (charged or converted photons) as a function of the centre-of-mass energy W . The trigger and reconstruction procedure is essentially the same as in our 1978 experiment. The expected cross section can be expressed in terms of a continuum

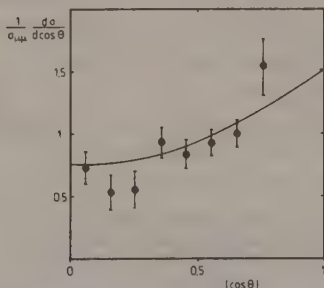


Fig. 2. Distribution of $|\cos \theta|$ for the selected $\mu^+ \mu^-$ events in the inner detector divided by the overall acceptance. The solid curve shows the $(1 + \cos^2 \theta)$ expectation.

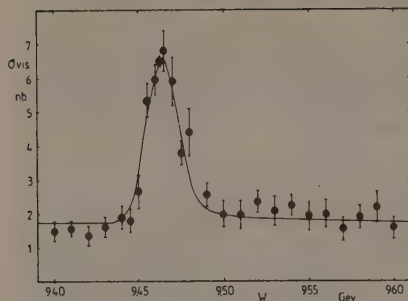


Fig. 3. Visible cross section for the reaction $e^+e^- \rightarrow \text{hadrons}$ with 4 or more charged or converted neutral particles. The data displayed are from the 1979 run alone and statistically independent from the 1978 data in refs. [2] and [5]. The solid curve is the result of a fit.

plus a Breit-Wigner contribution widened by the machine energy spread and radiative corrections [9, 10]. The detector acceptance on and off resonance has been determined with the help of a Monte-Carlo simulation three-jet and two-jet events [11]. A fit of the expected cross section to the data yields

$$\Gamma_{ee}\Gamma_{\text{had}}/\Gamma_{\text{tot}} = (1.23 \pm 0.09 \pm 0.20) \text{ keV}, \quad (4)$$

where the first error is statistical and the second error is systematic.

From the fit result as shown by the solid curve in fig. 3 we get the peak value for $\sigma(e^+e^- \rightarrow T \rightarrow \text{hadrons})$:

$$\sigma(e^+e^- \rightarrow T \rightarrow \text{hadrons}) = (10.1 \pm 0.7) \text{ nb}. \quad (5)$$

If we insert this value into eq. (2), we obtain

$$B_{\mu\mu} = (3.1 \pm 1.6)\%, \quad (6a)$$

Since this result is independent from our 1978 result [5], we average the two and obtain

$$B_{\mu\mu} = (2.9 \pm 1.3 \pm 0.5)\%, \quad (6b)$$

where the first error is statistical and the second is systematic. The result in eqs. (4) and (6b) may be combined to obtain Γ_{ee} and Γ_{tot} via eq. (1):

$$\Gamma_{ee} = (1.35 \pm 0.11 \pm 0.22) \text{ keV}, \quad (7a)$$

$$\Gamma_{\text{tot}} = (47^{+37}_{-15}) \text{ keV}, \quad (7b)$$

where the errors given on Γ_{tot} are one standard deviation statistical errors; the systematic error on Γ_{tot} is much smaller.

The total width of the $T(9.46)$ meson is found to be very close to the width of the J/ψ meson which is $(67 \pm 12) \text{ keV}$. This indicates that the nature of the two mesons is indeed very similar and that their decays are governed by the same mechanism. The dominant decay mode of both is the direct hadronic decay. Its width is obtained by subtracting $(N_1 + R)\Gamma_{ee}$ from Γ_{tot} , where N_1 is the number of lepton decay modes and R takes into account the hadronic decay through a virtual photon. For the J/ψ , $\Gamma_{\text{had, dir}}$ is about $(48 \pm 12) \text{ keV}$, and we obtain $(38^{+37}_{-15}) \text{ keV}$ for the $T(9.46)$.

The direct hadronic decay of $1^- Q\bar{Q}$ states has often been interpreted as a decay into three massless gluons which subsequently fragment into hadrons. In lowest order quantum chromodynamics [12], this rate is given by

$$\Gamma(Q\bar{Q} \rightarrow ggg) = \frac{10(\pi^2 - 9)\alpha_s^3}{81\pi e^2 Q^2} \Gamma(Q\bar{Q} \rightarrow e^+e^-). \quad (8)$$

Although the size of corrections to this expression due to higher orders and due to fragmentation is still unknown, we have nevertheless used it in order to see if its application to J/ψ and T decays leads to consistent values of the QCD coupling constant α_s . By inserting the experimental values of $\Gamma_{\text{had, dir}}$ as mentioned above into eq. (8) without any corrections, we find

$$\alpha_s(J/\psi) = 0.19 \pm 0.02, \quad (9a)$$

$$\alpha_s(T) = 0.17^{+0.04}_{-0.03}. \quad (9b)$$

We express our thanks to Dr. K. Wille and the DORIS group for their excellent work in operating the storage ring and to Professors E. Lohmann, H. Schopper and G.A. Voss for their support. We wish to thank A. Krolzig and all members of the F 51 group for the skilful technical help during the runs, and B. Hildebrandt for his help in data processing. The non-DESY members of the collaboration want to thank the DESY directorate for their hospitality. This work was supported in part by the Bundesministerium für Forschung und Technologie.

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THE HADRONIC CROSS SECTION OF ELECTRON-POSITRON ANNIHILATION AT 9.5 GeV AND THE T AND T' RESONANCE PARAMETERS

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The reaction $e^+e^- \rightarrow$ hadrons has been measured in the T and T' region using the DASP detector at the DESY storage ring DORIS. The following final results are obtained: $R_{\text{had}}(9.5 \text{ GeV}) = 3.73 \pm 0.16 \pm 0.28$, $\Gamma_{ee}(T) = (1.23 \pm 0.08 \pm 0.12) \text{ keV}$, $B_{\mu\mu}(T) = (3.2 \pm 1.3 \pm 0.3)\%$, $\Gamma_{ee}\Gamma_{\text{had}}/\Gamma_{\text{tot}}(T') = (0.55 \pm 0.11 \pm 0.06) \text{ keV}$, and $M(T') - M(T) = (556 \pm 10) \text{ MeV}$.

The production of T - and T' -mesons in e^+e^- annihilations was first observed at the DESY storage ring DORIS in 1978 [1–4]. Here we report new results on the $T'(10.02)$ meson and the hadronic R value at 9.5 GeV obtained with the DASP detector in a second run period in 1979/80. During this period data were also taken at the $T(9.46)$ meson [5], and the results of a final analysis of this state are presented in this paper.

The double-arm spectrometer DASP has been described before [6]. Basically it consists of a non-magnetic inner detector accepting a solid angle of about 50% of 4π , and of two outer magnetic spectrometer

arms covering about 5% of 4π . Both charged particles and photons are detected in either of the two components with good particle separation in the spectrometer arms.

DORIS was operated in a single ring, single bunch mode, as for the previous runs. We collected a total integrated luminosity of about 1600 nb^{-1} : 456 nb^{-1} on the T , 515 nb^{-1} on the T' , and 602 nb^{-1} in the neighbouring continuum regions. In order to get the resonance curves for e^+e^- annihilation into hadrons, energy scans were performed in the regions $9.4 < \sqrt{s} < 9.6 \text{ GeV}$ and $9.9 < \sqrt{s} < 10.1 \text{ GeV}$; $\sqrt{s}$ is the CM energy.

A clean sample of multi-hadron events in the inner detector was obtained only after a considerable reduc-

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tion of the recorded data. The trigger conditions and selection criteria are described in detail in refs. [7] and [8]. Cuts were applied to discriminate against background from beam-gas interactions, cosmic ray particles and synchrotron radiation, and against events from QED processes and two-photon interactions. In particular, the deposited energy had to be >800 MeV, and the number of reconstructed particles (charged or converted photons) was required to be ≥ 3 .

The efficiency of this data reduction procedure and the acceptance of the detector were determined by extensive Monte Carlo calculations. Events were generated both for the QED process $e^+e^- \rightarrow \ell^+\ell^-(\gamma)$ with $\ell = e, \mu, \tau$ [9], and for hadronic final states assumed to originate from the fragmentation of quark-antiquark pairs in the continuum, and of three-gluon states on the resonances. The fragmentation process was parametrized by the Field and Feynman jet model [10] and modifications thereof [11,12].

In the continuum, radiative corrections were incorporated into the Monte Carlo program by taking into account third order QED graphs in the event generation [9]. Thus the radiative corrections and the detector acceptance, including the data selection cuts, are calculated in a consistent way [8]. Fig. 1 shows the combined detector and reconstruction acceptance η , the radiative correction δ and the product $\eta(1+\delta)$ as a function of the energy of the radiated photon. Experimentally, the relevant quantity is $\eta(1+\delta)$ and this is insensitive to cuts in the photon energy. On the narrow resonances T and T' , we used the method of Jackson and Scharre [13] to determine the radiative corrections in conjunction with the storage ring resolution.

The contribution from τ pair production was determined by the same acceptance and radiation calculations and was subtracted from the hadronic cross section. The product $\eta(1+\delta)$ for τ pairs was obtained to be $(22 \pm 1)\%$. Contributions from $\gamma\gamma$ processes to the hadronic cross section were estimated to be $<1\%$ and are therefore neglected.

The integrated luminosity at each energy was determined by measuring the reactions $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \gamma\gamma$ in the inner detector, and independently by a luminosity monitoring system using small angle Bhabha scattering measured by four identical counter arms.

The determination of $R = \sigma(e^+e^- \rightarrow \text{hadrons})/$

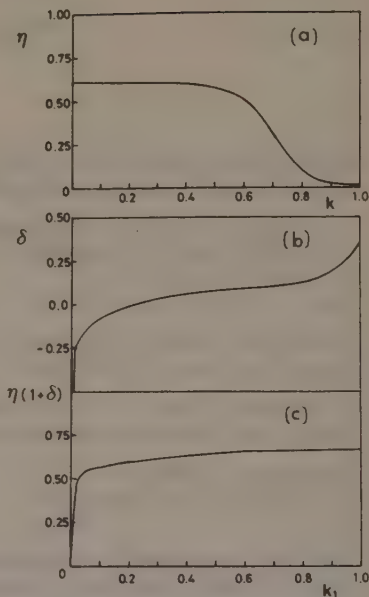


Fig. 1. Monte Carlo calculations of (a) the acceptance of $q\bar{q}\gamma$ events following Field-Feynman fragmentation [10] and Berends-Kleiss radiation [9] for fixed values of k , where $k = 2E_\gamma/\sqrt{s}$, (b) the radiative correction δ defined by $\sigma(e^+e^- \rightarrow \text{hadrons} + \gamma \text{ with } k < k_1) = (1 + \delta) \cdot \sigma_0(e^+e^- \rightarrow \text{hadrons}, k = 0)$, and (c) the experimentally relevant product $\eta(1 + \delta)$.

$\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ is based on 730 reconstructed events in the energy ranges 9.40–9.44 and 9.49–9.60 GeV. The second region has been corrected for the radiative tail of the T resonance following ref. [13]. The mean energy value is 9.51 GeV. We find

$$R = 3.73 \pm 0.16 \pm 0.28,$$

where the first error is statistical and the second is systematic. The systematic error contains 5% for the luminosity determination, 5% for the uncertainty on $\eta(1+\delta)$, 1% for τ subtraction, 2% for subtraction of other background sources and 1% for the T radiative tail.

The hadronic cross sections around the resonances are shown in fig. 2. The curves are the results of fitting

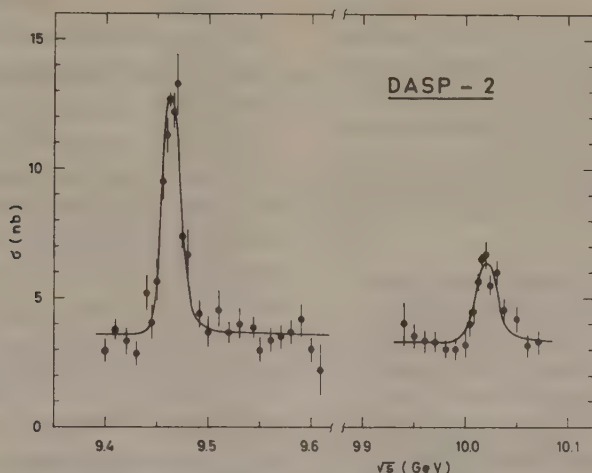


Fig. 2. Cross sections of the reaction $e^+e^- \rightarrow \text{hadrons}$ for the T and T' region as a function of the CM energy $\sqrt{s}$. The cross sections are corrected for the detector acceptance and in the continuum for radiation effects. The curves are the results of fitting a narrow resonance with gaussian resolution and radiative corrections according to ref. [13].

to the data an incoherent sum of a continuum curve varying like $1/s$ and a Breit-Wigner resonance function folded with gaussian machine resolution and radiation [13]. The resulting fit parameters are given in the columns two and three of table 1. The large systematic errors for the resonance masses reflect mainly the uncertainties of the energy calibration of DORIS. The mass values found in the first run period in 1978 [2,4,14] were about 6 MeV below the present values both for T and T' , whereas the mass difference stayed constant. The rms widths of the resonances agree with the energy resolution of DORIS (~ 9 MeV). Also given in table 1 are bounds and values for the muon-pair branching

ratio $B_{\mu\mu}$, the electronic width Γ_{ee} and the total width Γ_{tot} . The results for T are consistent with the values previously published [5], whereas $\Gamma_{\text{had}}\Gamma_{ee}/\Gamma_{\text{tot}}$ for the T' is nearly two standard deviations higher than our preliminary result [4].

The muonic branching ratio $B_{\mu\mu}$ on the resonances was determined by comparing the numbers of μ -pair events on and off resonance [7]. This was done independently for the inner and outer detector, and the results have been averaged. The value quoted in table 1 for the T meson, $B_{\mu\mu} = (3.2 \pm 1.3 \pm 0.3)\%$, is the final DASP-2 result, since it is the average over the two run periods.

Table 1
Resonance parameters.

	M (MeV)	$\Gamma_{\text{had}}\Gamma_{ee}/\Gamma_{\text{tot}}$ (keV)	$\Delta M(T', T)$ (MeV)	$B_{\mu\mu}$	Γ_{ee} (keV)	Γ_{tot} (keV)
T'	$10018 \pm 1.5 \pm 20$	$0.55 \pm 0.11 \pm 0.06$	556 ± 10	$< 6\%$ (95% CL)		> 9 (95% CL)
T	$9462 \pm 0.6 \pm 10$	$1.12 \pm 0.07 \pm 0.04$	556 ± 10	$(3.2 \pm 1.3 \pm 0.3)\%$	$1.23 \pm 0.08 \pm 0.12$	38^{+27}_{-11}

The systematic errors on R are still too large for extracting a value of α_s from first order QCD corrections. On the other hand, $B_{\mu\mu}$ is now so well known that its value may be used to determine α_s with the help of QCD calculations for $T \rightarrow ggg + gggg$ obtained by Mackenzie and Lepage [15]. Our value of the leptonic branching ratio of the T , combined with results from other experiments [16], leads to a world average of $B_{\mu\mu}(T) = (3.3 \pm 0.5)\%$. From this value, Mackenzie and Lepage obtain $\alpha_s(M_T) = 0.14 \pm 0.01$ and $\Lambda = (100^{+34}_{-25})$ MeV, where Λ is the QCD parameter in the $\overline{MS}$ renormalization scheme.

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A PRECISION MEASUREMENT OF THE T' MESON MASS

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ABSTRACT : The e^+e^- - storage ring DORIS II provides polarized beams with polarizations up to 80% in the energy range of the T' meson. The method of resonance depolarization allows the average beam energy to be determined to a precision of ± 0.1 MeV. An energy scan of the hadronic cross section over the resonance range with the detectors ARGUS and Crystal Ball determines the T' mass to be $(10023.1 \pm 0.4 \pm 0.5)$ MeV.

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We report here the results of a mass measurement of the T' meson using the method of resonance depolarization. This method has already been used to determine the mass of the T meson³⁾ at Novosibirsk. The T' experiment was performed from July 20 to July 24, 1983 at the electron-positron storage ring DORIS II. The result is of obvious spectroscopic interest. In addition, it will allow a better control of the beam energy for resonance data taking in the future.

Details of DORIS II are described elsewhere⁴⁾. The main operating characteristics for this experiment were as follows: electron and positron currents between 18 and 30 mA, peak luminosity at $1.5 \cdot 10^{31}/\text{cm}^2/\text{sec}$, beam life times of around 3.5 hours, and beam polarizations of about 80%.

In electron-positron storage rings, the beam particles become polarized by the Sokolov-Ternov effect⁵⁾. The polarization of the beams can be destroyed continuously by a weak time-dependent magnetic field^{6,7)}.

The frequency of this depolarizing field gives precise information on the mean energy of the beams as will be explained in the following.

The spins of the polarized particles precess around the vertical axis. The number of spin precessions per orbit revolution is $\gamma \cdot (g-2)/2$, where γ is the Lorentz factor and g is the magnetic moment of the electron. If a particle is kicked vertically by a radial magnetic field at a certain position of the ring, its spin is tilted forward or backward. If the radial field is time-dependent and in phase with the spin precession at the fixed ring position, the spin is rotated over many revolutions from the vertical into the horizontal direction, and the polarization is destroyed. The resonance condition for the frequency f_D of the applied depolarizing field is

$$\left| \frac{g-2}{2} \gamma \pm n \right| f_0 = f_D,$$

where n is any integer, 11 in our case, and f_0 is the orbit revolution frequency.

The block diagram of the DORIS depolarizer is shown in Fig. 1. The sine-wave generated by a highly precise frequency synthesizer is added to the input of a power amplifier which drives the vertical feedback coil in DORIS.

The maximum field integral of the coil is of the order of 0.1 Gauss meter. The synthesizer is swept over a frequency range, and the resulting beam polarization is measured for each sweep by the DORIS polarimeter⁸⁾.

The layout of the polarimeter is shown in Fig. 2. A circularly polarized laser beam is directed head-on against the electron beam. The vertical distribution of the backscattered photons shows an asymmetry which is proportional to the electron beam polarization. This asymmetry is measured by a lead-scintillator-sandwich shower counter with a movable slit in front.

Fig. 3 shows the result of a typical depolarization measurement. The curve gives the degree of polarization as function of the frequency. The average beam energy is then calculated from the resonance frequency by the formula given above. A frequency interval of ± 0.25 kHz corresponds to ± 0.11 MeV per beam, i.e. ± 0.22 MeV in the CMS energy of e^+e^- collisions. During the energy scan described below, different energies have been determined with different precisions.

The width of the depolarizing resonance is much smaller than the energy spread of the beam which is caused by quantum emission. The energy of each particle in the beam fluctuates around the average energy. The time of these fluctuations is small compared to the depolarization time, therefore the depolarizer averages over the energy fluctuations.

The cross section of the reaction

$$e^+e^- \rightarrow \text{hadrons}$$

is measured by the detectors ARGUS and Crystal Ball at 13 different CMS energies in the range from 9.96 to 10.04 GeV. A total integrated luminosity of about 2.0/pb has been collected by each of the two detectors.

ARGUS is a new magnetic spectrometer¹⁾ equipped with a central drift chamber, time-of-flight scintillators, shower counters and muon chambers. The trigger conditions and the selection criteria for hadronic events are described in Ref. 1. In addition to three well reconstructed charged particles pointing to the interaction point, a minimum total energy deposit of 1.7 GeV in the shower counters is required. This additional requirement speeds up the

reconstruction procedure and reduces considerably the contamination from τ pairs and from two-photon interactions. For each scan point, the number of selected hadronic events is divided by the number of Bhabha events in an angular range between about 20 and 160 degrees. This ratio determines the visible cross section shown in Fig. 4. In addition to the shown vertical error bars, which are of statistical origin only, there is an overall vertical scale error of about 10%, which has no influence on the mass determination. The ratio of subsamples of Bhabha events has been controlled to be constant within statistics for all scan points. Beam-gas or beam-wall background contributes less than 0.5% as has been checked with several separated beam runs during the scan. The horizontal error bars take into account the different precision with which the energy is determined by depolarization for each point.

The curve in Fig. 4 is the result of a four-parameter fit to the ARGUS data using the expression of Jackson and Scharre⁹⁾ for radiative corrections. The four parameters are the T' mass, the energy spread in DORIS, the continuum level and the peak cross section. The fit takes into account cross section errors as well as energy errors, since these are slightly different for each point as mentioned above. The fit results in $m(T') = (10023.43 \pm 0.45)$ MeV and a RMS width of the CMS energy of (8.2 ± 0.5) MeV. The quoted errors include the energy uncertainties on each scan point.

The Crystal Ball²⁾ detector consists mainly of a spherical segmented shell of NaI (Tl) shower counters which cover 93% of 4π solid angle. The coverage is increased to 98% of 4π by NaI (Tl) endcaps. The direction of charged particles is measured in 3 double layers of proportional tube chambers. The Crystal Ball in its configuration at SPEAR has been described in detail elsewhere¹⁰⁾; at DORIS the main detector is unchanged. For the detection of hadronic events it is used as a calorimeter. The thickness of the NaI (Tl) shell corresponds to 16 radiation lengths and to one interaction length for high energy pions. Therefore the distribution of energy deposited by charged hadrons peaks at around 200 MeV due to non-interacting minimum-ionizing charged particles and has a long tail caused by nuclear interactions. Neutral, electromagnetically decaying hadrons deposit all their energy in the detector.

The selection of hadronic events and the determination of the visible cross section was done with three different methods which gave compatible results. Two of the methods yielded results so rapidly that they were used to optimize the scan strategy during the run. In the following, one particular method is presented.

The events used in this analysis triggered the apparatus by passing a total-energy threshold at about 1800 MeV. The pattern of energy deposition was required to be symmetric with respect to the interaction point in order to remove cosmic ray and beam-gas events. A minimum of 5 detected particles (charged or neutral) was required. The latter cut also removed events due to the QED processes $e^+e^- \rightarrow e^+e^-$ and $e^+e^- \rightarrow \gamma\gamma$.

The contamination of the hadron sample due to cosmic ray and beam-gas events was measured with separated-beam runs which were distributed over the period of data taking and was found to be less than 2%.

The luminosity was measured in two ways. Firstly, a small angle luminosity monitor is used, which detects Bhabha scattering events in the range of $6^\circ - 10^\circ$ of the scattering angle. Secondly, the main detector is used to identify Bhabha and $e^+e^- \rightarrow \gamma\gamma$ events in the angular range given by $|\cos\theta| < 0.85$. The two luminosities agreed very well and their ratio was constant within errors over the run period.

The resulting visible cross section is shown in Fig. 5. Runs without depolarization energy measurement were not used. The data points were fitted with the same function as in Fig. 4 (solid line). The resulting mass value is (10022.8 ± 0.5) MeV, where the error is statistical only. The Gaussian width owing to the beam energy spread was found to be 8.1 ± 0.5 MeV. This analysis is preliminary.

The two beam width results agree with the expected DORIS resolution⁴⁾. The two mass results are averaged to give $m(T') = (10023.1 \pm 0.4)$ MeV. In combining the errors of the two experiments, it was taken into account that they are partly correlated owing to the common errors on the beam energy. The difference between the average beam energy determined by depolarization and the actual mean value in each of the two interaction areas is estimated to be small. A more detailed calculation of this effect is under way, an upper limit at present is ± 0.25 MeV/beam, resulting in

$$m(T') = (10023.1 \pm 0.4 \pm 0.5) \text{ MeV.}$$

Using the Novosibirsk value³⁾ for $m(T)$, $(9459.7 \pm 0.6) \text{ MeV}$, this result fixes the T' - T mass difference to

$$\Delta m = (563.4 \pm 0.9) \text{ MeV.}$$

This result is compared to previous ones in Table 1.

TABLE 1

The mass difference $m(T') - m(T)$ as determined by different experiments (in MeV).

DASP 2 ¹¹⁾	556 $\pm$ 10
LENA ¹²⁾	560 $\pm$ 10
CLEO ¹³⁾	560.7 $\pm$ 0.8 $\pm$ 3.0
CUSB ¹⁴⁾	559 $\pm$ 1 $\pm$ 3
ARGUS ¹⁾	561 $\pm$ 3
this experiment	563.4 $\pm$ 0.9

FIGURE CAPTIONS

- Fig. 1 Block diagram of the DORIS depolarizer.
- Fig. 2 Schematic view of the DORIS polarimeter.
- Fig. 3 Example of a depolarization curve. Horizontal error bars indicate the sweep range of the frequency generator.
- Fig. 4 The visible hadronic cross section over the T' resonance as measured in ARGUS.
- Fig. 5 The visible hadronic cross section over the T' resonance as measured in the Crystal Ball detector.

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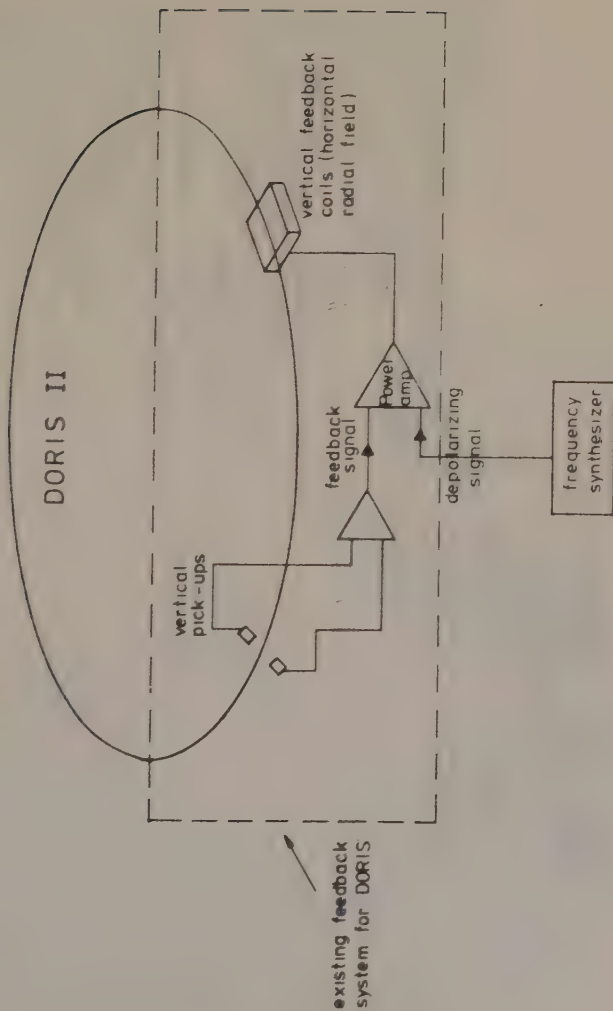


Fig. 1

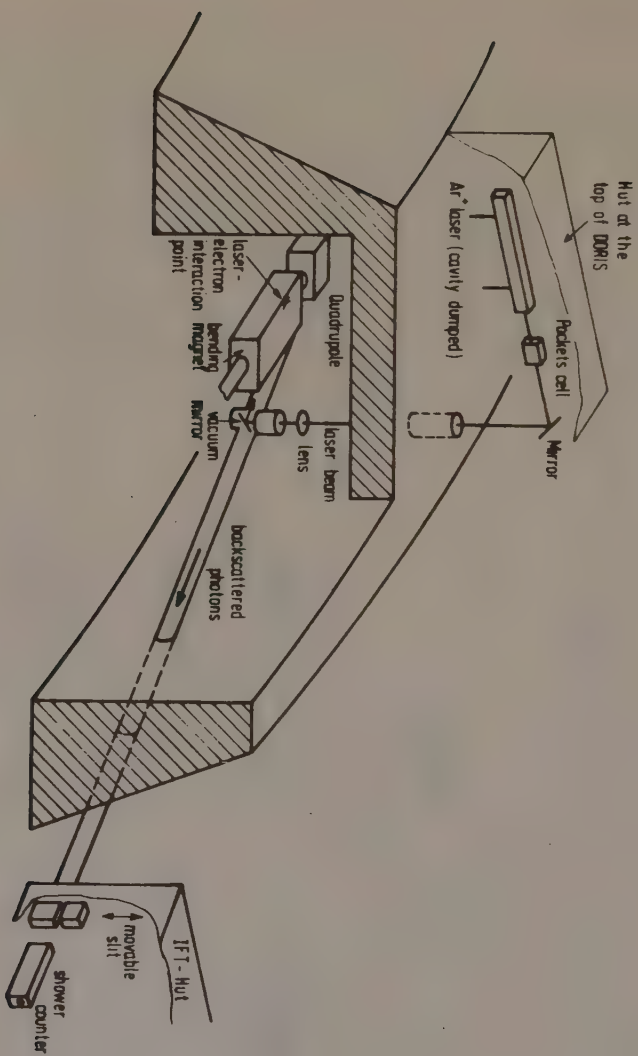


Fig. 2

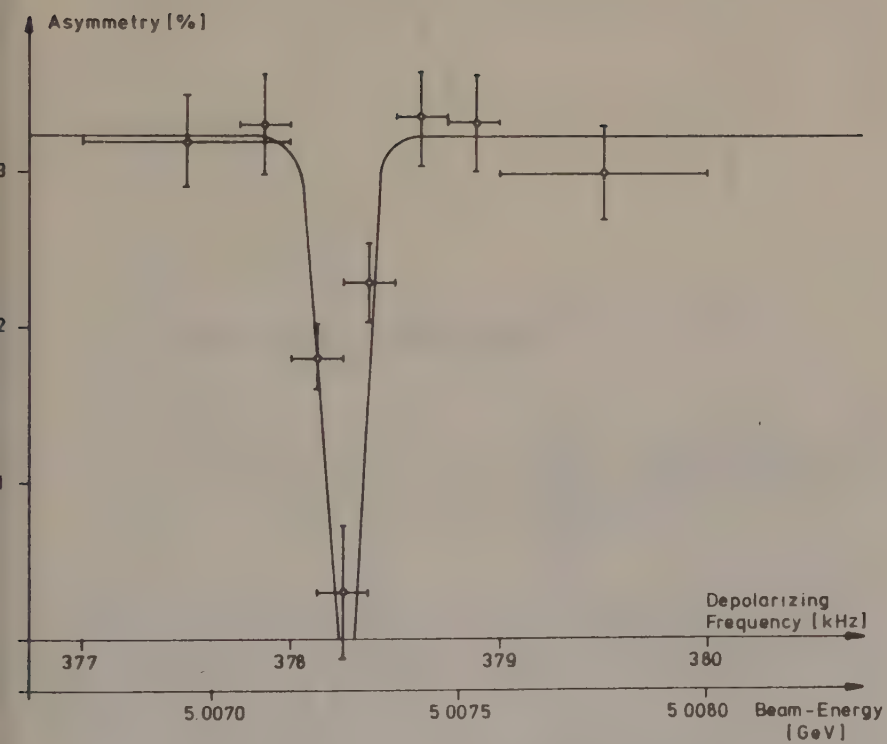


Fig. 3

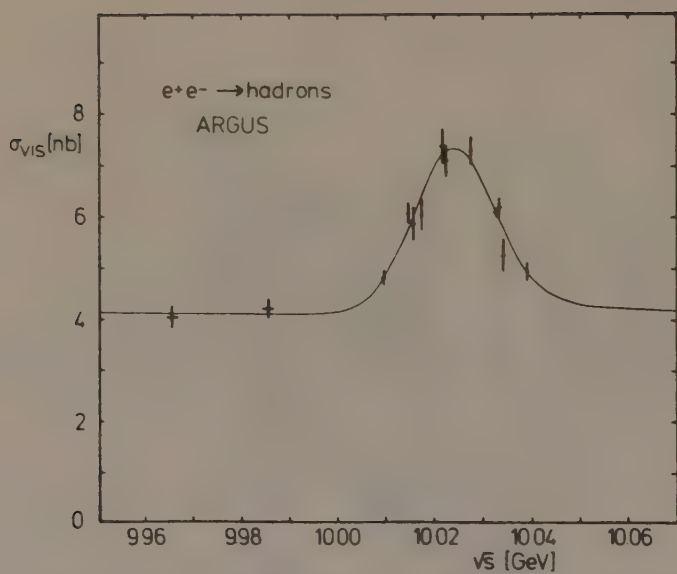


Fig. 4

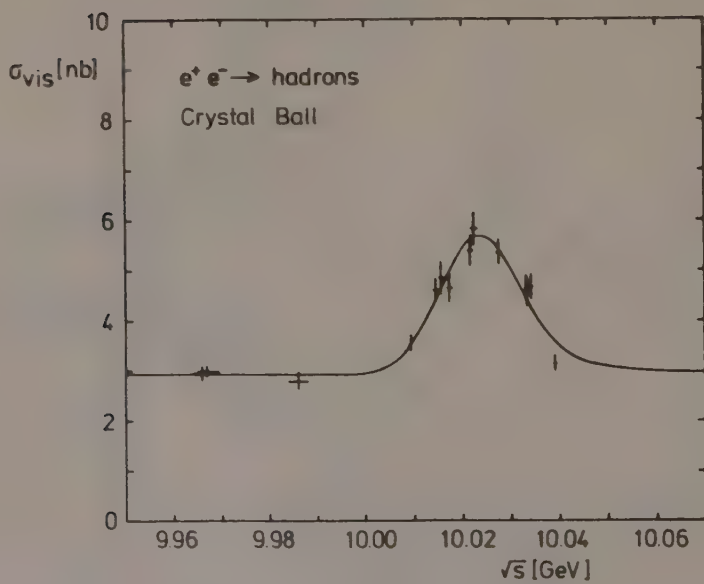


Fig. 5

INCLUSIVE HADRON PRODUCTION IN THE Υ -REGION

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Inclusive production of π^+ , K^+ and $\bar{p}$ has been measured in e^+e^- annihilation for center of mass energies between 9.4 and 10.1 GeV. The hadron yields on the resonances Υ and Υ' are compared to the off-resonance (continuum) yields with the aim of uncovering differences between three-gluon hadronization and quark-antiquark fragmentation. A noticeable difference is seen in the yield of protons and antiprotons which is $(8.1 \pm 2.1)\%$ of all charged hadrons for Υ decay and $(18.9 \pm 6.9)\%$ for Υ' decay compared to $(1.5 \pm 1.1)\%$ for non-resonant production.

Single particle inclusive cross sections of charged hadrons produced by e^+e^- annihilations have been measured in a number of experiments [1] over a wide range of the center of mass energy $\sqrt{s}$. One remarkable observation is the almost perfect scaling in s of the cross section $(s/\beta) d\sigma/dx$ for $x = 2E/\sqrt{s} \gtrsim 0.2$, where β is the velocity of the hadron and E its energy. In the quark-parton model approximate scaling is a consequence of the assumed quark-gluon structure.

It is believed that e^+e^- annihilation proceeds via an initial quark-antiquark pair fragmenting into the observed hadrons in the continuum. In contrast, intermediate quarkonium states such as J/ψ or Υ decay predominantly into three gluons which again fragment into

hadrons. Hence one might expect to find differences in the particle spectra from quarkonium decay and from non-resonant production. For this reason we have measured inclusive spectra for the production of charged pions, kaons and antiprotons on the resonances $\Upsilon(9.46)$ and $\Upsilon'(10.02)$ and in the near-by continuum,

The data were taken with the double-arm spectrometer DASP at the DESY storage ring DORIS. From the integrated luminosity collected between October 1979 and April 1980 we used 373 nb^{-1} on the Υ , 471 nb^{-1} on the Υ' and 515 nb^{-1} in the neighbouring continuum regions.

The DASP detector consists of a non-magnetic inner part accepting a solid angle of about 50% of 4π , and a magnetic outer detector covering about 5% of 4π . The

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outer detector, used for this analysis, consists of two identical spectrometer arms equipped with proportional chambers, Čerenkov counters, spark chambers, time-of-flight counters, sandwich shower counters and range counters behind an iron shield. A detailed description of the apparatus can be found in ref. [2].

An inclusive trigger was employed requiring a charged particle in one of the spectrometer arms. A considerable reduction in background, mainly from beam-gas interactions, was achieved by demanding at least one charged track also in the other arm or in the inner detector where in addition a minimum energy deposition of 500 MeV was required. This cut affects the inclusive trigger only slightly. Its efficiency was found to be 98% both for two- and three-jet Monte Carlo events [3]⁺¹ run through a simulated detector.

The particles collected by the spectrometer arms were separated into $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, p and $\bar{p}$. Leptons were identified by exploiting the information of the shower counters, Čerenkov counters and iron absorbers. By means of time-of-flight measurements pions can be discriminated on a 95% confidence level from kaons up to momenta of 1.5 GeV/c, and protons (antiprotons) from pions and kaons up to 2.6 GeV/c. Most of the hadrons still coming from beam-gas interactions were eliminated by requiring that the reconstructed vertex lies within the interaction volume. This volume was determined from Bhabha scatters measured at the same time. The remaining beam-gas background was extrapolated into the interaction region and subtracted from the final hadron spectra, amounting to < 11% for pions, < 5% for kaons, and < 2% for antiprotons. Since the majority of the protons come from beam-gas interactions, only antiprotons were considered, assuming the proton yield to be the same as the yield for antiprotons.

The remaining hadrons, 1258 pions, 135 kaons and 39 antiprotons, were corrected for π and K decays in flight, absorption by the detector material, misidentification of hadrons as leptons and failures in the track reconstruction. A detailed evaluation of these corrections is given in ref. [5]. The momentum dependent acceptance of the spectrometer arms and the efficiencies of the various counters were taken into account. The spectrometer arms cover polar angles between

$\cos \theta = -0.5$ and $+0.5$. The extrapolation to the full angular range, which is needed for integrating the inclusive cross sections over θ , was performed by a Monte Carlo calculation. From two-jet Monte Carlo events a momentum independent correction of + 6% was obtained, which we applied to the continuum spectra. For T and T' decays, simulated by three-jet events, the correction is zero.

Hadrons from τ decay were subtracted from the spectra by means of Monte Carlo calculations. Radiative corrections were applied [6] amounting to - 4% practically independent of momentum. Most of the low-energy muons from the two-photon process $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ cannot be identified by the range counters. However, we verified that they are rejected by the above selection criteria.

The integrated luminosity was determined from Bhabha scattering measured independently in the inner and outer detector as described previously [7].

Fig. 1 shows the invariant cross section $E d^3\sigma/dp^3$ as a function of the hadron energy E for $\pi^\pm$ (i.e. the sum of π^+ and π^-), $K^\pm$ and twice the $\bar{p}$ production in the three regions of interest. The on-resonance cross sections refer to direct decays of T and T' only. Contributions from the non-resonant background and from vacuum polarization have been subtracted using $\sigma_{\text{dir}} = \sigma_{\text{on}} - \sigma_{\text{off}} (\sigma_{\mu\mu}^{\text{on}}/\sigma_{\mu\mu}^{\text{off}})$. According to QCD, the direct decays obtained in this way are essentially decays into three gluons.

The invariant cross sections can be approximated by an exponential, $E d^3\sigma/dp^3 \propto \exp(-bE)$. From a least-squares fit we get $b = 4.4 \pm 0.3 \text{ GeV}^{-1}$ for non-resonant pion production. This value agrees with the slope parameters for pion production in the continuum measured at other energies [2]⁺², as shown in fig. 2. The slope appears to fall slightly, weaker than $1/\sqrt{s}$, with the center of mass energy.

The pion spectrum from direct T decay has a slope which is practically equal to the continuum value, if fitted over the entire measured energy range. However, its lower part ($E < 1 \text{ GeV}$) falls off faster, with $b = 4.9 \pm 0.2 \text{ GeV}^{-1}$.

The average number of charged pions, kaons and antiprotons can be calculated by a numerical integration of the measured spectra. Using for $R = \sigma_h/\sigma_{\mu\mu}$ the

⁺¹ In particular, we used the jet model versions of Sjöstrand et al. [4].

⁺² The slope parameter b at 12 GeV was calculated from data in ref. [12].

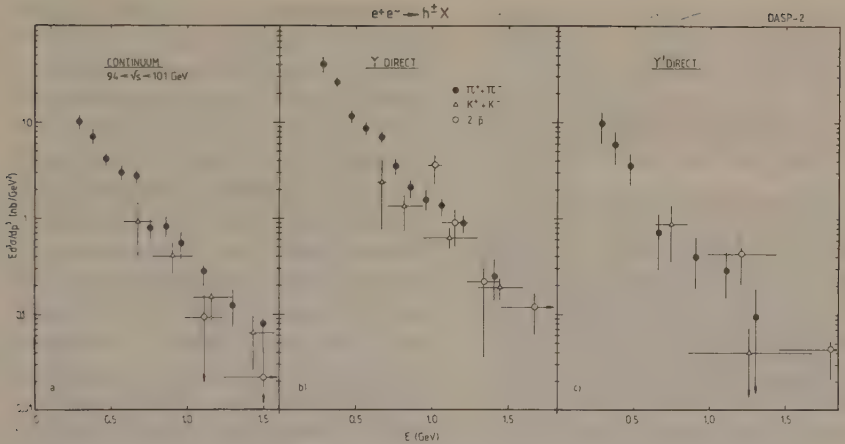


Fig. 1. Invariant cross sections $E \frac{d^3\sigma}{dp^3}$ as a function of particle energy E for the sum of π^+ and π^- , K^+ and K^- and twice the $\bar{p}$ production in the continuum (a), and for direct decays of Υ (b) and Υ' (c).

value measured in this experiment [8], $R = 3.6 \pm 0.2$, and the exponential fits described above in order to extrapolate to zero energy, we find a total charged hadron multiplicity of 6.9 ± 0.6 in the continuum and

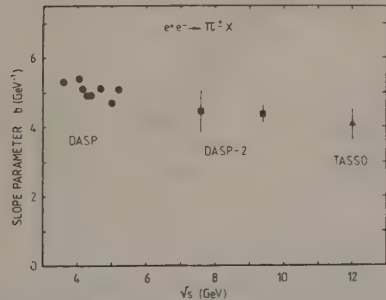


Fig. 2. Slope parameter b versus $\sqrt{s}$ for non-resonant π^+ production obtained from exponential fits to the invariant cross sections, $E \frac{d^3\sigma}{dp^3} \propto \exp(-bE)$. Data points are from DASP [2], TASSO [7], and this experiment, where the point at 7.6 GeV was obtained from unpublished data.

7.9 ± 0.6 for direct Υ decay, in agreement with other experiments [9,10]. The average fraction of the center of mass energy carried by the charged hadrons was calculated in the same way as the average multiplicity. We obtain $\langle E_{\text{ch}} \rangle_{\text{off}}/\sqrt{s} = (51.8 \pm 8.0)\%$ in the continuum and $\langle E_{\text{ch}} \rangle_{\text{on}}/\sqrt{s} = (48.0 \pm 3.6)\%$ for direct Υ decays, in agreement with results from PLUTO [11].

The invariant cross sections of the three types of hadrons in the continuum and on the Υ resonances are close together (cf. fig. 1). However, antiproton production appears to be more abundant on resonance than off resonance. The ratio between the yields of $2\bar{p}$ and all charged hadrons is indeed as high as $(8.1 \pm 2.1)\%$ for direct Υ decay compared to $(1.5 \pm 1.1)\%$ in the continuum. This increase of $(6.6 \pm 2.4)\%$ has a statistical significance of 2.8 standard deviations. A similar effect of 2.5 standard deviations is found for direct Υ decays.

The fractions of the various charged particles are summarized in table 1. Using the mean charged multiplicity as determined above, the average number of antiprotons per event comes out to be $\langle \bar{p} \rangle = 0.32 \pm 0.08$ on the Υ , and $\langle \bar{p} \rangle = 0.05 \pm 0.03$ in the continuum.

Table 1
Particle ratios in the momentum range $0.3 < p < 1.5$ GeV/c.

	$2\bar{p}$	$K^{\pm}$	$\pi^{\pm}$
continuum	0.015 ± 0.011	0.183 ± 0.039	0.802 ± 0.059
T	0.081 ± 0.021	0.154 ± 0.027	0.765 ± 0.048
T'	0.189 ± 0.069	0.119 ± 0.072	0.692 ± 0.129

It is interesting to note that a similar rise in the anti-proton yield has been seen on the J/ψ [2]. In the continuum, a large production of (anti)baryons has recently been reported by PETRA groups around 30 GeV [12]. Since it is believed that gluon emission processes become appreciable at this energy and that, on the other hand, the J/ψ and T states decay primarily via three gluons, one may wonder whether more copious baryon production is connected with gluon fragmentation.

In fig. 3a the continuum scaling cross section (s/β)

$\times d\sigma/dx$ for charged pions produced near the T resonance is compared with the cross sections measured by DASP at 5.2 GeV [2] and by PETRA experiments at 12 and 30 GeV [12]. Although approximate scaling is expected only for $x \gtrsim 0.2$, the cross sections of all experiments agree within a factor of two even down to $x = 0.05$ where our data start to overlap that of the other experiments. If we use $x_p = 2p/\sqrt{s}$ instead of $x = x_E = 2E/\sqrt{s}$, the cross sections $s d\sigma/dx_p$ for all charged hadrons scale very well with s for $x_p \gtrsim 0.2$, as can be seen from fig. 3b. The enhanced DASP cross section which appears in the x_E spectrum, shows up here as a shoulder around $x_p = 0.35$.

In summary we find a very similar behavior of the invariant and scaling cross sections for inclusive charged pion, kaon and antiproton production on and near the T resonance. The most prominent difference is a rise seen in the antiproton yield at the T and T' resonances. This effect of about three standard deviations, which was also seen in the J/ψ region deserves a more

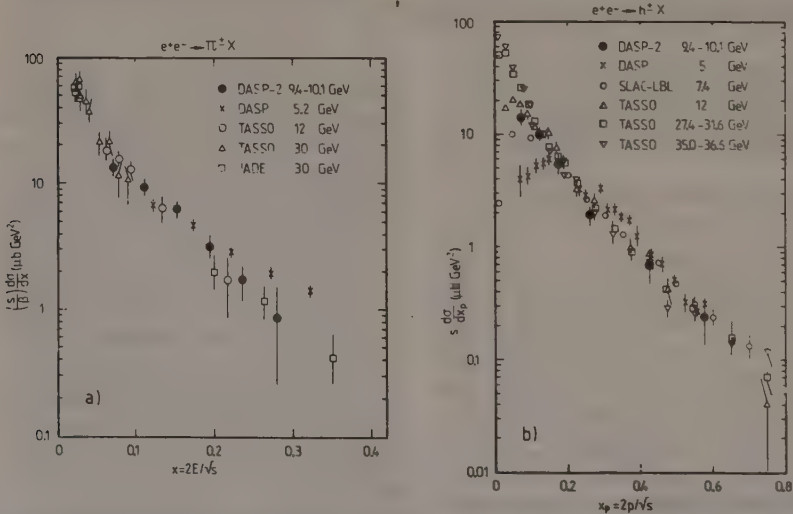


Fig. 3. (a) The scaling cross section (s/β) $d\sigma/dx$ versus $x = 2E/\sqrt{s}$ for charged pion production in the continuum near the T including the spectra measured at other energies by DASP [2], TASSO and JADE [12]. (b) The quantity $s d\sigma/dx_p$ versus $x_p = 2p/\sqrt{s}$ for charged hadrons as measured in this experiment, by DASP [2], by SLAC-LBL [13] and by TASSO [12].

thorough investigation both theoretically and experimentally.

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Branching Ratio and Mass Spectrum of the Decay $T' \rightarrow T \pi^+ \pi^-$

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Abstract

The reaction $e^+e^- \rightarrow T' \rightarrow T \pi^+\pi^-$, with $T \rightarrow$ anything, has been measured using the ARGUS detector at DORIS. We obtain a mass difference $M(T') - M(T) = (562 \pm 3) \text{ MeV}$ and a decay branching ratio $BR(T' \rightarrow T \pi^+\pi^-) = (17.9 \pm 0.9 \pm 2.1)\%$. The invariant mass spectrum of the $\pi^+\pi^-$ system differs from phase space, but is well described by a matrix element of the form $(M_{\pi\pi}^2 - \lambda M_\pi^2)$ with $\lambda = 2.6 \pm 0.5$. We also report preliminary results on the exclusive decay $T' \rightarrow T \pi^+\pi^-$, with $T \rightarrow e^+e^-$, and obtain $BR(T \rightarrow e^+e^-) = (2.8 \pm 0.4 \pm 0.3)\%$.

We report here the first results obtained with the ARGUS detector at DORIS. ARGUS is a magnetic spectrometer consisting of a solenoid with a field of 0.8 T, a cylindrical drift chamber with 5940 sense wires arranged in 36 layers, a time-of-flight system with 64 scintillators in the barrel region and with 48 scintillators in each endcap, a shower detection system with 1280 lead-scintillator-sandwich counters in the barrel region and 240 in each endcap, and a muon identification system with 1744 proportional counter tubes. The spectrometer is shown schematically in Fig. 1, and details of its performance are given in Ref. 1.

The decay $T'(10023) \rightarrow \pi^+\pi^- T(9460)$ has been studied both theoretically and experimentally. The QCD description^{2,3,4)} of this process assumes that the excited $b\bar{b}$ system T' decays into the T state by the emission of two gluons in their lowest multipole state. This picture leads to a prediction for the invariant mass spectrum of the $\pi^+\pi^-$ system. Experimentally, the decay has been studied by two different methods. The first involves reconstruction of the secondary decays $T \rightarrow e^+e^-$ and $T \rightarrow \mu^+\mu^-$ with about 3% branching ratio each. The second method uses the missing mass spectrum of the $\pi^+\pi^-$ system which includes all secondary T decays and therefore increases the number of $T' \rightarrow T\pi\pi$ decays available for study by a factor of about 16.

Both methods have been used to determine the $T' \rightarrow T\pi^+\pi^-$ branching ratio^{5,6,7)}. Because of the high combinatorial background arising from the second method, only the first could be used to study the invariant $\pi\pi$ mass spectrum, but the data obtained was too limited for detailed tests. The good momentum resolution

for charged particles in ARGUS, which presently is $\sigma(p)/p \approx 0.012 \sqrt{(1+p^2 c^2/\text{GeV}^2)}$, allows us to apply the missing mass method for both the branching ratio and the invariant mass spectrum and to test the QCD prediction.

For this experiment, we have analyzed T' decays from a data sample with 13 events/pb and an off-resonance sample at 9.980 GeV with 1.6 events/pb. The events were collected requiring either one of three different triggers in coincidence with a bunch crossing signal :

- 1.) " E_{tot} ", defined by an energy deposit of > 800 MeV in each of the two z-hemispheres (see Fig. 1) of the shower calorimeter,
- 2.) " ≥ 3 tracks", where each track is defined in two steps by
 - a) a fast coincidence between groups of time-of-flight and shower counters, and b) a slow coincidence using track masks in the drift chamber. The shower counter information is used to require at least one track in each z-hemisphere. For the data sample analyzed here, all three tracks are required to lie in the barrel region with $|\cos\theta| < 0.75$.
- 3.) "2 quasicollinear tracks", basically the same as trigger 2, except that events with only two tracks are accepted if these tracks differ in azimuth by more than 120° .

Typical trigger rates were 4 Hz, typical luminosities $10^{31}/\text{cm}^2/\text{sec}$. Multi-hadron events were selected off-line by requiring ≥ 4 reconstructed tracks in the drift chamber with an acceptable fit for five parameters θ , ϕ , p_t , z_0 and d_0 . θ and ϕ are polar and azimuthal angles, p_t is the transverse momentum, z_0 is the z coordinate of the track's closest point to the z-axis, and d_0 is the distance of this point to the z-axis. Cuts of $|z_0| < 8$ cm and $d_0 < 1.5$ cm were applied to each track. This procedure yields 76825 multi-hadron events on the T' resonance and 5774 in the continuum at 9.98 GeV.

For the resonance events, $\pi^+\pi^-$ pairs are formed by combining all oppositely charged particles with $|\cos\theta| < 0.90$ and $p_t > 80$ MeV/c. Energy loss in the beam tube and in the inner drift chamber wall is taken into account. The missing mass of each pair is calculated by assuming that the particles are

pions and that the T' is at rest with a mass of 10023.5 MeV^{8,9)}. The resulting distribution is shown in Fig. 2. We observe a prominent peak at the mass of the T , the FWHM of which is 7 MeV.

From the position of the peak, the $T'-T$ mass difference is determined to be (562 ± 3) MeV. The error is purely systematic and arises mainly from the present uncertainty in the ARGUS magnetic field. The result agrees well with values from DORIS^{10,11)}, CESR^{12,13)} and VEPP-4⁸⁾ which were all obtained from beam energy measurements at the formation energies of the resonances. The results are compared in Table 1.

The number of entries in the peak determines the $T' \rightarrow T\pi^+\pi^-$ branching ratio. For this determination, we use a subsample of 7.48 events/pb, which contains $N_R = 32084$ selected multihadron events and 4637 entries in the 16 MeV wide missing mass range around the T peak. The combinatorial background under the peak is calculated from a third order polynomial fit to the mass spectrum on both sides of the peak. The fit gives 3111 ± 32 background entries, leaving $N_S(T' \rightarrow T\pi^+\pi^-) = 1526 \pm 75$ selected $T' \rightarrow T\pi^+\pi^-$ decays.

The evaluation of the branching ratio

$$BR(T' \rightarrow T\pi^+\pi^-) = \frac{N_S(T' \rightarrow T\pi^+\pi^-)/\eta(T' \rightarrow T\pi^+\pi^-)}{N_S(T')/\eta(T' \rightarrow \text{anything})}$$

requires the number of selected T' events, $N_S(T')$, and the acceptance values η . $N_S(T')$ is obtained from $N_S(T') = N_R - N_C \cdot L_R/L_C$, where N_R was given above, $N_C = 5774$ is the number of selected multihadron events off resonance, and L_R/L_C is the ratio of the integrated luminosities on and off resonance. This ratio is obtained from Bhabha events in an angular range from 20 to 160 degrees. The contribution from τ pairs and two-photon reactions to N_R and N_C is not evaluated, since their cross sections are the same at the resonance and in the continuum. Beam-gas or beam-wall event contributions have been determined to be negligible from studies of separated beam runs. We obtain $N_S(T') = 14615 \pm 310$.

The two acceptances are determined from a Monte Carlo calculation simulating detector performances, trigger conditions, event reconstruction and selection cuts. For the $T' \rightarrow T\pi^+\pi^-$ decays, the invariant $\pi\pi$ mass spectrum is generated according to phase space weighted by $(M_{\pi\pi}^2 - 2M_\pi^2)^2$. This form is in agreement with our results as will be shown later. All decays are assumed to be isotropic. For the decays $T' \rightarrow$ anything, we generate an appropriate mixture of e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$ ¹⁴⁾, ggg , $P_b\gamma$ ¹⁵⁾ and $T\pi\pi$ decays. The simulation gives $\eta(T' \rightarrow T\pi^+\pi^-) = 0.49$ and $\eta(T' \rightarrow \text{anything}) = 0.84$ with systematic errors of ± 0.05 in both values.

We obtain $BR(T' \rightarrow T\pi^+\pi^-) = (17.9 \pm 0.9 \pm 2.1)\%$, where the first error is the statistical error in $N_S(T' \rightarrow T\pi^+\pi^-)$ including background subtraction, and the second error is systematic. The result is in good agreement with previous results as shown in Table 2.

All 76825 events on the T' resonance are used for a determination of the $\pi^+\pi^-$ invariant mass spectrum. For each pair of particles with opposite charges, fulfilling the above selection criteria, both the missing mass and the invariant mass are calculated. Missing mass spectra are plotted for 15 bins of the invariant mass, and the number of $T' \rightarrow T\pi^+\pi^-$ events in each missing mass spectrum is obtained in exactly the same way as was done for the branching ratio analysis. The result is shown in Fig. 3, where the errors are statistical only. The experimental resolution of the invariant mass is ± 4 MeV (RMS) as determined by the Monte Carlo simulation.

The $\pi\pi$ invariant mass spectrum in Fig. 3 is markedly different from the phase space distribution, shown by the dashed curve, but is similar to the spectrum found for the $\psi' \rightarrow J/\psi \pi^+\pi^-$ decay ¹⁶⁾. This similarity indicates that the theoretical methods ^{17,2,3,4)} developed for describing ψ' decays are also applicable to T' decays. The QCD motivated models of Yan ²⁾, Voloshin-Zakharov ³⁾ and Novikov-Shifman ⁴⁾ lead to very similar predictions for the $\pi\pi$ mass spectrum. We have compared these three parametrizations to our data, and all fit the data equally well as shown in Table 3. The solid curve in Fig. 3 represents the three best fits, since they are equal within the drawing precision. We conclude, that QCD describes the $T' \rightarrow T\pi\pi$ decay correctly, that there are differences between T' and ψ' decays (the latter preferring $\lambda \approx 4$), and that the $\pi\pi$ resonance description for ψ' decays ¹⁸⁾ is not valid for T' decays.

Finally, we add a preliminary result obtained from the study of the exclusive decays $T' \rightarrow T\pi^+\pi^-$, $T \rightarrow e^+e^-$. Using the T' subsample with 4.78 events/pb, we find 41 such exclusive events. The selection criteria for the pions have been described above, electrons are selected by comparing their momentum in the drift chamber to their energy in the shower counters. In order to minimize rejection due to radiation of the electrons, only a soft cut of $p(e^\pm) > 1.5$ GeV/c has been applied. The Monte Carlo simulation gives an acceptance of 0.51 ± 0.05 for the selected $T' \rightarrow \pi^+\pi^-e^+e^-$ events. From these results and from our value for $BR(T' \rightarrow T\pi^+\pi^-)$, we obtain the electronic branching ratio of the $T(9460)$ meson, $BR(T \rightarrow e^+e^-) = (2.8 \pm 0.4 \pm 0.3)\%$, where the first error is statistical and the second error is systematic. Table 4 compares our result to earlier results. The derived world average is in good agreement with the average ²¹⁾ for $BR(T \rightarrow \mu^+\mu^-)$, $(2.7 \pm 0.4)\%$, thus confirming lepton universality in T decay.

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FIGURE CAPTIONS :

- Fig. 1 Schematic view of the ARGUS detector. 1 = Muon chambers, 2 = shower counters, 3 = Drift chamber, 4 = Time-of-flight counters, 5 = Mini beta quadrupoles, 6 = Iron yoke, 7 = Solenoid coils, 8 = Compensation coils.
- Fig. 2 Missing mass spectrum of the $\pi^+\pi^-$ system from 76825 selected events on the T' resonance assuming an T' mass of 10023.5 MeV.
- Fig. 3 Invariant mass spectrum of the $\pi^+\pi^-$ system from 4200 selected decays $T' \rightarrow T \pi^+\pi^-$, $T \rightarrow$ anything, corrected for the weakly mass-dependent acceptance. The dashed curve is the phase space expectation, the solid curve corresponds to the three best fits of the QCD parametrizations given in Table 3. Both curves are normalized to the total number of events.

TABLE 1

The mass difference $m(T') - m(T)$ as determined by different experiments (in MeV).

DASP-2 ¹⁰⁾	556 ± 10
LENA ¹¹⁾	560 ± 10
CLEO ¹²⁾	$560 \pm 0.8 \pm 3.0$
CUSB ¹³⁾	$559 \pm 1 \pm 3$
VEPP-4 ⁸⁾	563.2 ± 0.6
this experiment	562 ± 3

TABLE 2

The branching ratio of the decay $T' \rightarrow T \pi^+ \pi^-$ as determined by different experiments (in percent).

LENA 5)	19 ± 8
CUSB 6)	20 ± 7
CLEO 7)	$19.1 \pm 3.1 \pm 2.9$
this experiment	$17.9 \pm 0.9 \pm 2.1$

TABLE 3

The fit of three different QCD parametrizations to the $\pi\pi$ invariant mass spectrum in the $T' \rightarrow T \pi^+ \pi^-$ decay.

	Rate / Phase Space	$\chi^2(\text{NDF}=13)$	Result
Yan 2)*,	$(M_{\pi\pi}^2 - 2 M_{\pi}^2)^2$ $+ \frac{1}{3} \frac{B}{A} (M_{\pi\pi}^2 - 2 M_{\pi}^2)$ $\cdot [(M_{\pi\pi}^2 - 4 M_{\pi}^2)$ $+ 2 (M_{\pi\pi}^2 + 2 M_{\pi}^2) K_O^2 / M_{\pi\pi}^2]$ $+ o (B^2/A^2)$	18.6	$B/A =$ -0.09 ± 0.07
Voloshin-Zakharov 3)	$(M_{\pi\pi}^2 - \lambda M_{\pi}^2)^2$	18.5	$\lambda = 2.6 \pm 0.5$
Novikov-Shifman 4)	$[M_{\pi\pi}^2 - \kappa (M_{T'} - M_T)^2$ $\cdot (1 + 2 M_{\pi}^2 / M_{\pi\pi}^2)]^2 + o (\kappa^2)$	19.0	$\kappa = 0.12 \pm 0.02$

*) $K_O = (M_{T'}^2 + M_{\pi\pi}^2 - M_T^2) / 2 M_{T'}$

TABLE 4

The branching ratio of the decay $T(9.46) \rightarrow e^+e^-$ as determined
by different experiments (in percent)

PLUTO ¹⁹⁾	5.1 ± 3.0
LENA, CUSB, CLEO ²⁰⁾	3.5 ± 0.8
this experiment	$2.8 \pm 0.4 \pm 0.3$
average	3.0 ± 0.4

ARGUS

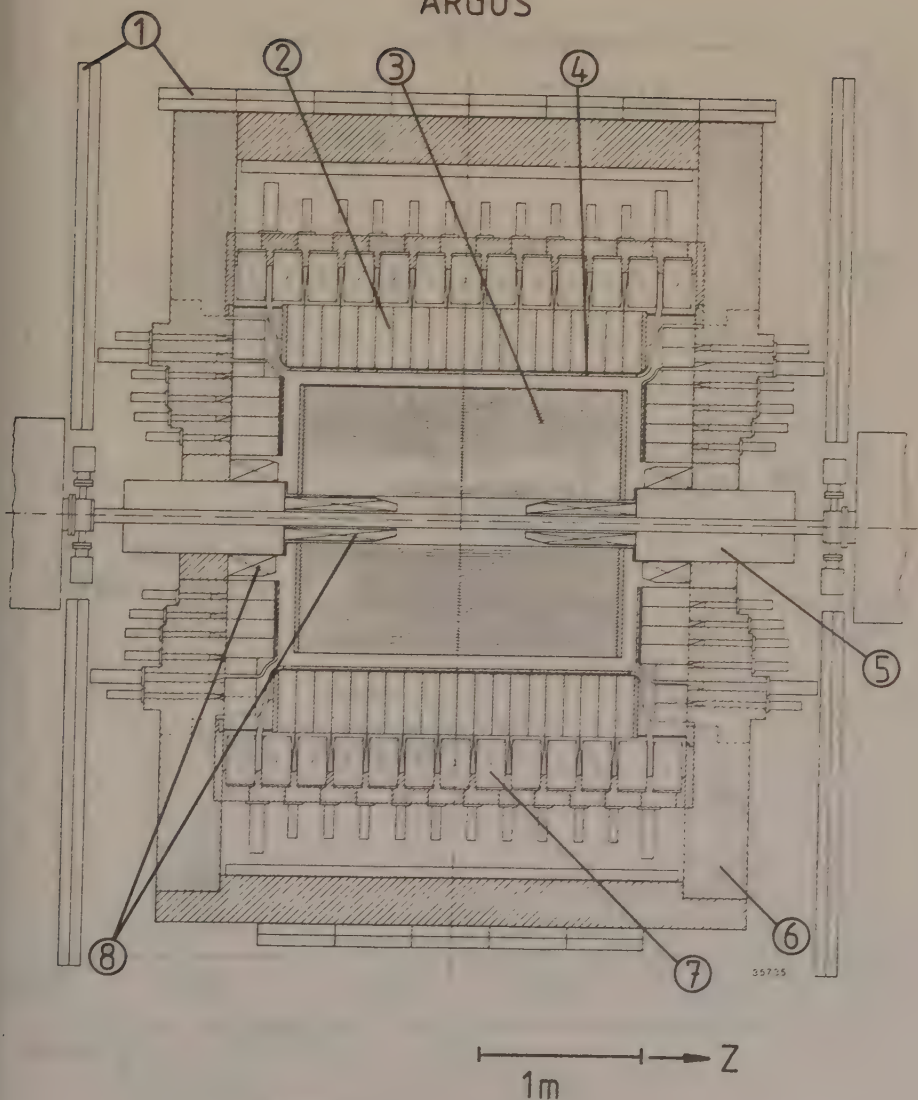


Fig. 1

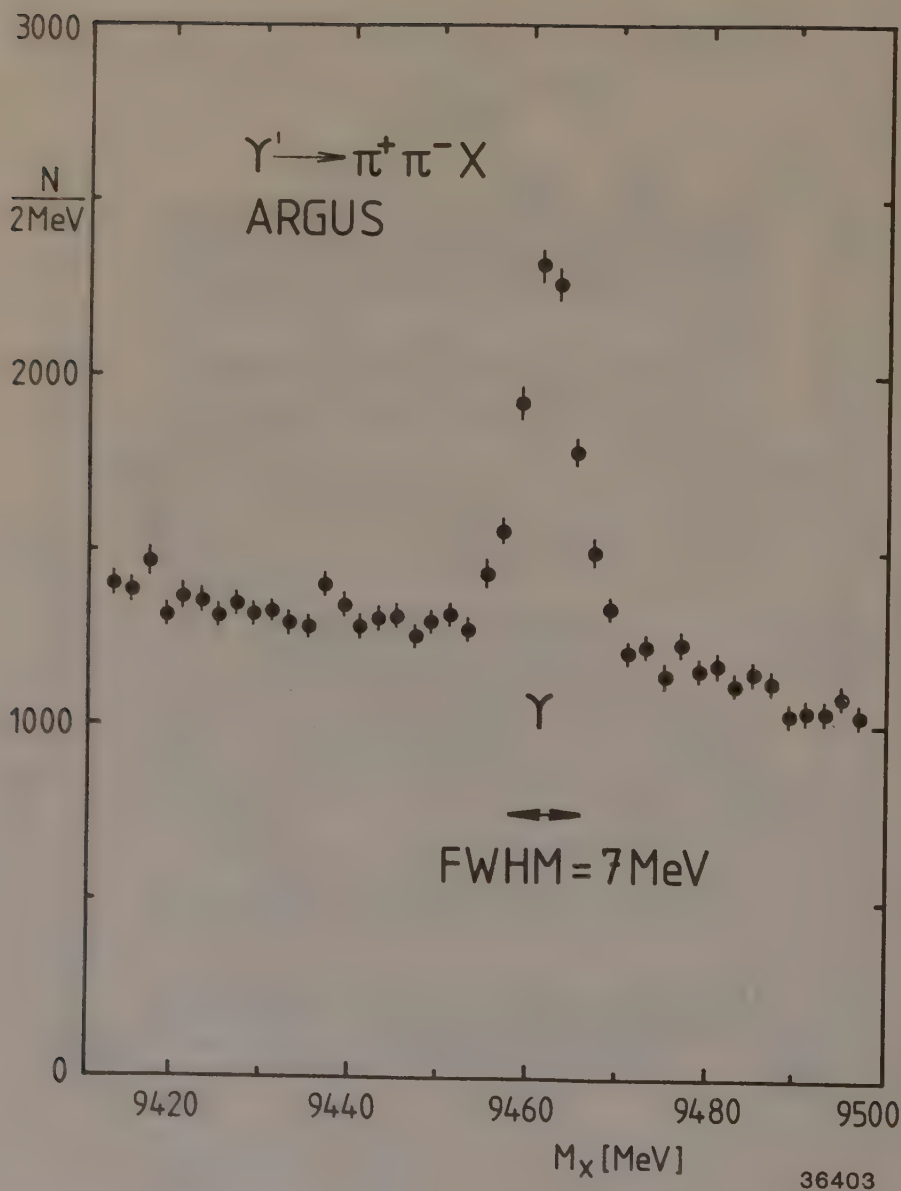


Fig. 2

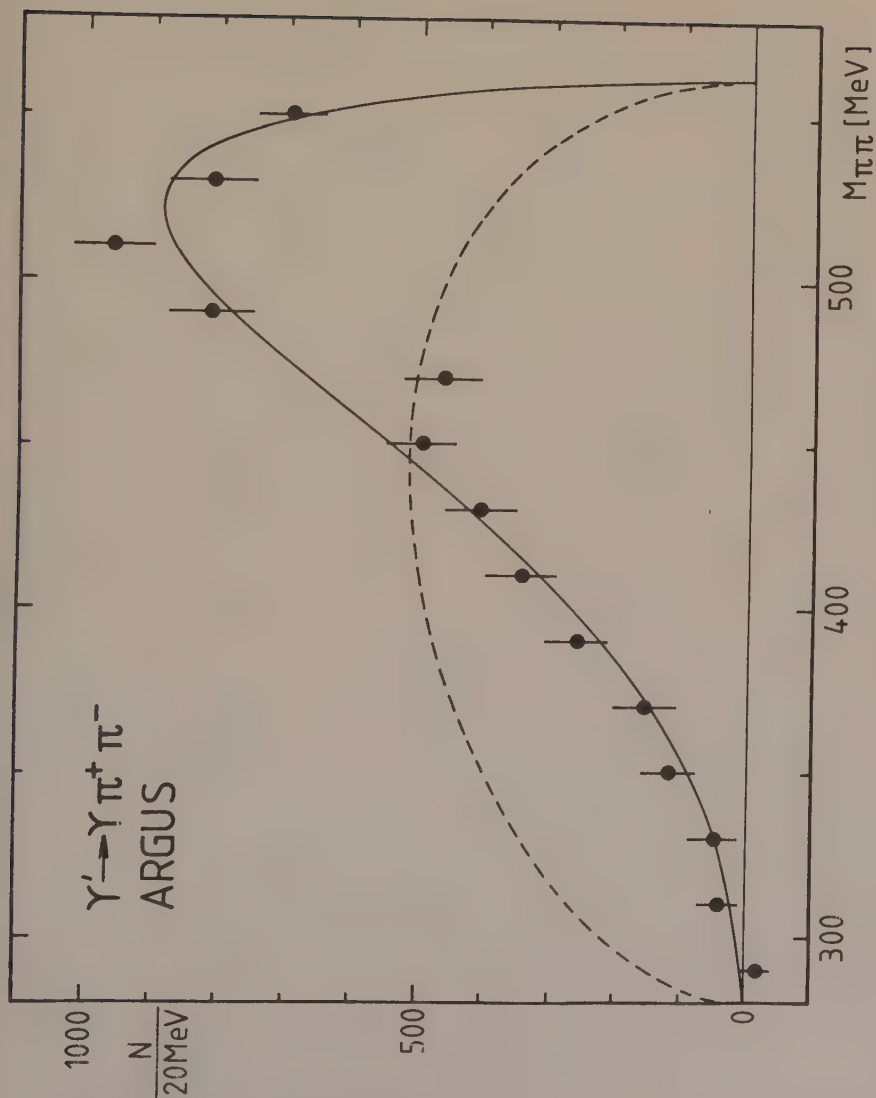


Fig. 3

